THE FEASIBILITY OF INTEGRATED PEST MANAGEMENT

ON POTATOES IN ONTARIO

D. J. Madder and M. Stemeroff

1985

Ontario Pesticides
Advisory Committee

Hon. Jim Bradley
Minister

ISBN NO. 0-7729-5775-4

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TABLE OF CONTENTS

	Page No.
TERMS OF REFERENCE	viii
ACKNOWLEDGEMENTS AND LIMITATIONS	ix
TABLE OF CONTENTS	iii
SUMMARY	vi
1. INTRODUCTION	1
1.1 PRODUCTION SETTING	1
1.2 RESEARCH AND EXTENSION COSTS ASSOCIATED WITH PEST CONTROL OF POTATOES	3
2. BIOLOGY AND SIGNIFICANCE OF PESTS TO POTATO PRODUCTION	5
2.1 INSECTS	5
2.1.1 Foliage Feeding Insects	5
2.1.2 Root and Tuber Feeding Insects	8
2.1.3 Losses Caused By Insects	9
2.2 DISEASES	13
2.2.1 Losses Caused By Diseases	17
2.3 WEEDS	18
2.3.1 Losses Caused By Weeds	18
2.4 NEMATODES	19
2.4.1 Losses Caused By Nematodes	20
3. CURRENT CONTROL TACTICS USED ON POTATOES	23
3.1 INSECTS	23
3.2 DISEASES	28
3.3 WEEDS	33
3.4 NEMATODES	37
4. PROBLEMS ASSOCIATED WITH CURRENT CONTROL TACTICS USED ON POTATOES	38
4.1 PESTICIDE RESISTANCE	38
4.2 GROUND WATER CONTAMINATION WITH PESTICIDES	40
4.3 COSTS OF PEST CONTROL	41
5. POTENTIAL TECHNIQUES FOR USE IN INTEGRATED PEST MANAGEMENT ON POTATOES	45
5.1 INSECTS	45
5.1.1 Pest Monitoring Techniques And Economic Thresholds	45
5.1.2 Potential Control Techniques	50
5.1.3 Host Plant Resistance	53
5.1.4 Cultural Control Measures	55
5.1.5 Insecticides	57
5.2 DISEASES	58
5.2.1 Pest Monitoring Techniques And Economic Thresholds	58
5.2.2 Potential Control Techniques	62
5.3 WEEDS	65
5.3.1 Pest Monitoring Techniques And Economic Thresholds	65
5.3.2 Potential Control Techniques	65

Page No.

5.4 NEMATODES 66
5.4.1 Pest Monitoring Techniques And Economic Thresholds 66
5.4.2 Potential Control Techniques 68

6. POTENTIAL OF IMPLEMENTATION OF IPM ON POTATOES 70
6.1 EFFECT OF AN IPM PROGRAM ON POTATO PRODUCTION 71
6.2 POTATO CROP MANAGEMENT 72

7. RESEARCH RECOMMENDATIONS 74

REFERENCES 75

PERSONAL COMMUNICATIONS 83

APPENDIX 1. PARTICIPANTS IN THE SCIENTIFIC MEETING, SEPTEMBER 1984, TORONTO, ONTARIO

APPENDIX 2. POTATO CROP MANAGEMENT PROGRAM, ALLISTON

LIST OF FIGURES

1. Insecticide Cost per Bushel in A - Onions, B - Apples and C - Potatoes 42

LIST OF TABLES

1. Production Costs for Potatoes grown in Ontario, 1984 2

2. Yield Losses in Potatoes Due to Insects, Weeds and Diseases in Ontario 12

3. Influence of Soil Fumigants on Numbers of the Root Lesion Nematode in Potato Fields 21

4. Influence of Soil Fumigants on Yields of Potatoes 22

5. Insecticides Registered and Recommended for Use on Potatoes in Ontario 25

6. Insecticides Currently Recommended for Insect Control on Potatoes in Ontario 26

7. Typical Grower Insecticide Use on Potatoes in the Alliston and Shelburne Regions of Ontario in 1984 27

8. Fungicides Registered and Recommended for use on Potatoes in Ontario 29

9. Currently Recommended Fungicides for the Control of Foliar Diseases on Potatoes 30

		Page No.
10.	Estimated Grower Fungicide Use on Potatoes in the Alliston and Shelburne Regions of Ontario in 1984	30
11.	Cultivar Sensitivity/Tolerance to Selected Diseases of Potatoes Commonly Grown in Ontario	31
12.	Herbicides Registered and Recommended for Use on Potatoes in Ontario	34
13.	Currently Recommended Herbicides for Use on Potatoes in Ontario	35
14.	Estimated Herbicide Use by Potato Growers in the Alliston and Shelburne Regions of Ontario in 1984	36
15.	Direct Contact Toxicity of Three Insecticides to Three Strains of Colorado Potato Beetle from Southwestern Ontario in 1980	39
16.	Pesticide Costs ($US/hectare) in Michigan and New York State	43
17.	Total Pesticide Costs (per hectare) for Selected Crops in Canada ($Canadian)	44
18.	Colorado Potato Beetle Spray Guidelines as Used in Rhode Island and Long Island, U.S.A.	47
19.	Ranking of Potato Varieties for Susceptibility to Late Blight	60

SUMMARY

Culice Incorporated was asked to study the feasibility of an integrated pest management program for use on potatoes in Ontario. To this end, a scientific meeting was held on 24 September, 1984. Participants in the meeting included research, extension, and marketing personnel, as well as potato growers. Information discussed at that meeting, as well as published papers, unpublished data, extension information and conversations with research and extension personnel and potato growers were used to compile this report.

A large variety of insects, weeds, diseases and nematode pests attacks potatoes in Ontario. Losses due to uncontrolled pest populations can be in excess of 60 percent of marketable yield. Frequent application of pesticide is, in most instances, the only measure used to control these pests. Several significant problems are associated with this intensive use of pesticides on potatoes including: the development of pesticide resistance; ground water contamination with pesticides; and increasing costs of pest control. This has led to the question as to whether an IPM program could decrease the risk of losses due to pests and thus reduce the problems associated with intensive pesticide use.

A variety of pest monitoring techniques and economic thresholds is currently available, or under development, for use in potatoes. However, none of these techniques has been tested in Ontario. It is evident that pesticides will remain the cornerstone of pest control in potatoes for some time, although some additional or alternative control techniques are available or under development for insect and disease control. Many of these techniques have not been tested in Ontario. While there is evidence that an IPM program has the potential to reduce the current problems in pest control in potatoes, several significant gaps in knowledge should be addressed prior to the commercial implementation of an IPM program in potatoes.

Potato growers and extension personnel are very receptive to the concept of an IPM program to aid them in decision making. In response to this interest by growers, a commercial pest management program is operating in the Alliston region as a component of a crop management program. Unfortunately, information concerning pest monitoring techniques and economic thresholds available for this program has not been tested. Further, due to a lack of available alternatives, the only pest control tactic available in almost all situations is the use of pesticides.

An overview of the major findings is provided in the section 6 of this report, "Potential Of Implementation Of IPM On Potatoes". The reader is strongly encouraged to scan this brief section as well as the section 7, "Research Recommendations". The remaining portions of this report provide the basis for the recommendations and other supporting information.

TERMS OF REFERENCE

The terms of reference of this contract between the Ontario Pesticides Advisory Committee and Culice Incorporated are to discuss:

1. the methods available for pest monitoring on potatoes;
2. the methods available for the control of pests on potatoes;
3. the economic thresholds available for pests on potatoes;
4. the attitudes held by extension and research personnel concerning the feasibility of implementing IPM on potatoes;
5. the economics of implementing and maintaining an IPM program on potatoes in Ontario.

ACKNOWLEDGEMENTS AND LIMITATIONS

This report is a compilation of information collected from published articles, non-refereed publications, extension information from Ontario, other Canadian provinces and the northeastern United States, and from numerous conversations with research and extension personnel and potato growers in Ontario. Information was also derived from a scientific meeting concerning the feasibility of an IPM program on potatoes in Ontario that was held in Toronto on 24 September, 1984. The participants in that meeting are listed in Appendix 1. We sincerely acknowledge the help of all participants in this meeting and the many people who have aided in this study. However, all errors and omissions are the responsibility of the authors.

We have attempted to fulfill the terms of reference of this study within the confines of time and finances available. This study is extensive in nature, and thus some subjects broached have not been covered in depth. A detailed discussion of seed potato production was not undertaken due to the relatively small hectarage of potatoes grown (7%) in relation to table stock production, and the unique problem of controlling virus vectors. This is not intended to imply that potato seed production is not significant, but that time and resources were limiting.

1. INTRODUCTION

1.1. PRODUCTION SETTING

Ontario produces 330,000 to 350,000 tonnes of potatoes annually. Of this total, approximately 50% are produced for processing, primarily for the production of chips, with smaller amounts for french-fries and "instant" products. The other 50% is used for tablestock (43%) and seed potato production (7%). The primary factor that usually limits yield in Ontario is a lack of adequate precipitation in July and early August. This is being overcome with the installation and use of irrigation equipment on an increasing number of potato fields.

Approximately 15,000 ha are used for potato production in Ontario. Of this total, about 38% of the potato hecterage is located in Simcoe County. Another 38% is located within Essex, Lambton, Middlesex, Elgin, Brant, Hamilton-Wentworth and Dufferin Counties. Most of the remaining hecterage (24%) is distributed among the rest of the southern Ontario counties. In the seven counties listed above, potato growers generally operate farms of 20 ha or more, in which potato production usually provides the main source of income.

Ontario consumes more potatoes than it produces. While some potatoes are exported, most are consumed within the province. The price paid to the grower is determined by the interaction between international supply and demand. Thus, when international supplies are scarce, the Ontario price is high and, conversely, when there is an over-supply, the price is reduced. There are two provincial marketing boards for potatoes in Ontario, namely: (1) the Ontario Potato Growers' Marketing Board (processing); and (2) the Ontario Fresh Potato Growers' Marketing Board. The processing marketing board is empowered to negotiate price, terms and conditions of sale for processing potatoes.

However, the fresh potato marketing board is strictly a promotional board for tablestock potatoes, with the primary objective to stimulate and improve the marketing of potatoes.

The Ontario potato market is quite complicated with supplies available from local farms, the Maritime provinces, and the United States. The market is dominated by supplies from these sources in the following pattern each year:

a) Up to June 15 the only new potatoes available are from the United States, mainly California and Florida;

b) From June 15 to about September 1, "early" potatoes supply most of the Ontario market and some production is sent out of the province;

c) Ontario "late" potatoes are present on local markets for the remainder of the season, although they retain a hold on the larger city markets only during the fall and early winter;

d) Maritime potatoes maintain the city markets during the winter months and usualy sell af a premium over local supplies. Continuity of supply is one reason why Maritime potatoes are preferred by wholesalers and retailers (Squire, pers. comm).

TABLE 1. Production Costs for Potatoes Grown in Ontario, 1984.

VARIABLE COSTS	**$/Hectare**
Hired labour	136
Seed	630
Fertilizer	265
Lime	43
Equipment operating costs	468
Interest on operating capital	196
Marketing Fees	44
Pesticides	**400**
FIXED COSTS	
Operator labour	100
Equipment	599
Land	263
Taxes	12
Other	145
TOTAL	**3,261**

Source : OMAF, 1984

On average, in 1984 it cost $3,261/ha to produce potatoes in Ontario (Table 1). Together, all crop protection pesticides amounted to approximately $400/ha, or 12% of the total cost of production. In addition to chemical costs, application costs amounted to approximately $20-$25/ha/-application. On this basis, average total application costs were approximately $150/ha, not including the costs of granular insecticide application. The total pesticide and application costs were on the order of $550/ha/year.

1.2 RESEARCH AND EXTENSION COSTS ASSOCIATED WITH PEST CONTROL ON POTATOES

In addition to pesticide and application costs, there are also research and extension costs associated with crop protection on potatoes in Ontario. There were 0.6 to 0.8 extension personyears associated with pest control on potatoes in Ontario in 1984 (Shaw, pers. comm.). This includes a number of OMAF extension personnel throughout the province, with much of the work done by S. Squire in Alliston. In Ontario, the number of extension personyears devoted to crop protection on potatoes has remained relatively constant over the past 15 years (Shaw, pers. comm.). Based on an average cost of $60,000/personyear, this represents a cost of $36,000 to $48,000 per year in 1984 dollars.

B. Coffin (pers. comm.) estimates that total research personyears devoted to crop protection on potatoes in Ontario ranged from 0.5 to 0.75 personyears in 1984. Based on an average cost of $120,000 per personyear, this represents a cost of $60,000 to $90,000 per year in 1984 dollars. The number of personyears devoted to research on weed control in potatoes, as listed by the Ontario Pest Control Research Committee (1985), is 0.11. The primary people involved are C. Swanton at Ridgetown

College of Agricultural Technology and V. Sousa-Machado, University of Guelph. A breakdown of research personyears devoted to insect, disease and nematode control is not provided in the Ontario Pest Control Research Committee report (1985). However, conversations with researchers in Ontario indicate that a total of approximately 0.5 personyears is devoted to research in this area. The primary people involved in this research include C. R. Harris, D. G. R. McLeod, and J. H. Tolman at the Agriculture Canada Research Centre in London; T. H. A. Olthof and J. Potter at the Agriculture Canada Research Station at Vineland; and M. K. Sears at the University of Guelph. There is very little current work being done concerning diseases of potatoes. It is estimated that no one person devotes more than 0.1 personyears to research concerning pest control/IPM on potatoes. The specific work that is being done by the above researchers is referred to in the appropriate sections of this report.

2. BIOLOGY AND SIGNIFICANCE OF PESTS TO POTATO PRODUCTION

A large number of pests reduce yield, interfere with harvest and/or lower the quality of the potato crop in Ontario. Several of these pests can individually cause crop losses from 50 to 100% if allowed to develop unchecked in favorable conditions (eg. Colorado potato beetle, early and late blight, annual and perennial grasses).

2.1. INSECTS

Potatoes are attacked by a wide variety of insect pests including the Colorado potato beetle, flea beetles, the potato stem borer, stalk borers, blister beetles, cutworms, grasshoppers, aphids, the tarnished plant bug, leafhoppers, psyllids, white grubs, wireworms, and seedcorn maggots. While all of these can cause damage, only the insects that are most significant in Ontario will be discussed below.

2.1.1. Foliage Feeding Insects

The two insects which cause the most significant defoliation of potatoes are the Colorado potato beetle and the potato flea beetle. The Colorado potato beetle is considered the most destructive insect pest of potatoes in many regions of Northeastern United States and Canada. It overwinters as the adult in soil at depths up to 25 cm. Upon emergence in the spring, adults feed and mate, and females oviposit on early planted potatoes. Adult emergence and feeding often correspond to the time of crop emergence in the spring. The eggs are usually deposited on the undersides of leaves in masses of 10 - 40. An adult female can deposit more than three hundred eggs in its life span of 4 - 5 weeks. The eggs hatch in approximately a week and the larvae pass through 4 instars in 3 - 4 weeks. The fully developed larvae drop off the leaves and usually pupate in the ground. The pupal stage lasts from 5-10 days.

There are 2 generations per year in Ontario, with peak adult emergence of the summer generation in July. While potatoes are the preferred host, the beetles may feed and survive on other members of the nightshade family including eggplant, tomato, tobacco and a variety of weed species. Within the solanums, alkaloids and glycoalkaloids appear to play the major role in determining host suitability.

Destruction of foliage by the feeding of the Colorado potato beetle reduces photosynthetic capacity, and thus, reduces marketable yield. These beetles are voracious feeders with fourth instar larvae consuming more that 500 square mm/day and adults from 130 - 1,200 square mm/day. Complete defoliation and even injury to the haulms can result.

Potato flea beetles overwinter as adults. In the spring, the adult females lay eggs just below the soil surface near host plants. The eggs hatch and the larvae feed on potato roots, and occasionally, tubers. The larval stage usually requires 4 - 5 weeks to complete development. Pupation occurs in the soil, and requires 7 - 10 days. The entire life cycle usually requires 4 - 6 weeks and there are 2 generations per year in Ontario. The primary damage is caused by the feeding of the over-wintered adults in the spring when newly emerged potato seedlings may not have sufficient leaf area to withstand the feeding damage. In severe infestations, the feeding of the second generation adults in August and September may also cause destruction and premature senescence of foliage and reduction in yield. Flea beetles may also transmit some diseases caused by viruses.

The most significant sap-feeding insects that attack potatoes in Ontario include the potato leaf hopper, green peach aphid, and the tarnished plant bug. The potato leaf hopper does not overwinter in Canada but disperses into the province from the United States arriving on potatoes in July. Eggs are laid in slits made by the female's ovipositor in leaf veins and stems of the potato plants. The eggs hatch in 7 - 10 days into nymphs that require several weeks to complete development. There are 2 - 3 generations per year in Ontario. Both nymphs and adults feed on the undersides of leaves and extract plant sap. This alone does not usually cause significant damage, rather, toxins secreted during feeding cause "Hopper-burn" that results in loss of photosynthetic tissue, occlusion of vascular elements, early senescence of foliage and reduced yields. Both nymphs and adults produce these toxins, with late nymphal instars causing much more damage than adults. Damage is first evident as a small brown triangular spot at the leaf tip. The margin of the leaf turns brown and rolls inward. Usually older leaves are first affected, however severe infestations will effect all leaves. Potato leaf hoppers may also be of significance in transmitting a variety of diseases in potatoes. In many parts of Ontario, the potato leaf hopper can be the most significant insect attacking potatoes.

On a world basis, aphids are considered to be the insect pests of greatest economic importance to potato production. Their primary importance is as vectors of viruses, although high populations may cause direct losses. Viruses transmitted to potatoes grown for table stock rarely affect yield or quality if the plants are innoculated with a virus after initiation of tuber-formation. However, a high incidence of virus in the seed potatoes used to produce table stock can result in losses in yield approaching 100%. Therefore, in Ontario, aphids are considered significant pests in seed potato production. A detailed discussion of the biology of aphids attacking potatoes is provided in Radcliffe (in press).

The green peach aphid has a large host range that includes potatoes. The green peach aphid overwinters in the egg stage, with early-spring generations developing on alternative hosts. It appears on potatoes in mid-July and has multiple generations through the rest of the season. Feeding by this aphid causes wilting, distortion of foliage and may result in the transmission of leafroll, rugose mosaic and mild mosaic viruses. Other aphids that may be of significance on potatoes include the buckthorn aphid, foxglove aphid, and the potato aphid.

The tarnished plant bug has a wide host range that includes potatoes. The tarnished plant bug overwinters as an adult, and feeds on weed hosts in the spring. Eggs are laid in plant tissues including florets. The eggs hatch in approximately 10 days, and the nymphs develop to adults in 3 - 4 weeks. There are 3 generations per year in Ontario, the most significant being the second generation that attacks potatoes in bloom. Feeding by tarnished plant bugs at that time results in flower blast, new growth is arrested, and yield may be reduced. Feeding may also result in transmission of the viruses which causes spindle tuber.

2.1.2. Root and Tuber Feeding Insects

Insects which may attack the tuber itself include cutworms, wireworms, white-grubs and seed-corn maggots. While they are not often major pests, significant reductions in crop quality have resulted from infestations of these insects.

Cutworms overwinter either as pupae or adults in Ontario, or they may disperse into the province from southern regions. They usually have 1 or 2 generations per year. Cutworms may cause defoliation, damage to the haulms and/or direct damage to the tubers themselves.

Wireworms overwinter as adults or larvae and have a 2 - 5 year life cycle. They feed on seed pieces and may kill the plants or retard their growth. Feeding on tubers results in the formation of pits and holes in seed pieces and tubers which allow the entry of pathogens such as rhizoctonia and blackleg. Damage is most severe following a crop rotation from sod.

White-grubs overwinter as larvae and have a 3 year life cycle. Eggs are laid from mid-May through June in patches of weeds or in grass. The eggs hatch in 2 - 3 weeks and feed over a 2 year period on roots and tubers. The final year is spent as pupae and adults in the soil. Damage is most severe following crop rotation from sod. Damage is similar to that caused by wireworms.

Seed-corn maggots overwinter as pupae, and have 3 - 4 generations per year. They are most active when decaying plant residue or manure is present, especially in cool, wet seasons. The eggs of the first generation are laid in May or June where decaying vegetable matter is plentiful. The eggs hatch in 2 - 3 days. The maggots mature in 7 - 12 days and pupate in the soil. The pupal stage requires 2 - 3 weeks to complete development. The maggots usualy attack the seed piece through unhealed injuries or diseased surfaces.

2.1.3. Losses Caused By Insects

Studies concerning the effect of defoliation as a result of insect feeding (Colorado potato beetle or flea beetles) on yield of potatoes indicate that yield reductions are not necessarily proportional to insect density or defoliation during the growing season (Hare, 1980; Wellik et al. 1981; Ferro et al. 1983; Cranshaw and Radcliffe, 1980; Shields and Wyman, 1984). Until initiation of tuber-bulking, there can be almost

complete compensation for all levels of defoliation. However, defoliation during tuber-bulking results in substantially reduced yield. Thus, those insects that cause most of their damage early and/or late in the season are generally not as significant as those that cause damage in mid-season during tuber formation and bulking.

Studies concerning the effects of potato leaf hopper feeding have shown that close linear relationships exist between increasing leaf hopper numbers, percent hopperburn and decreasing yield (Peterson and Granovsky, 1950; Sanford and Webb, 1977). No studies could be found that attempt to quantify yield or quality losses associated with tuber feeding insects.

In North America, losses in yield and quality of potatoes due to insects have been estimated to be 22% from 1910 to 1935, 16% from 1942 to 1951, and 10 - 12% in 1975. Without insecticides, it is estimated that losses in potato yield would increase by at least 30%. For example, average estimated losses caused by Colorado potato beetles in thirteen studies, despite the best control efforts, were approximately 1% vs. 47 $\pm$ 10% if no control measures were used (Schwartz and Klassen, 1981). In the same review it was estimated that based on data from six studies, losses despite best control of potato leaf hoppers were less than 1% vs. losses of 43 $\pm$ 19% if control measures were not used.

Tolman *et al.* (1986) studied the potential losses due to insects attacking potatoes in Ontario. Kennebec potatoes grown on sandy clay loam or on organic soil received one of five pesticide treatments:

1) insecticide plus fungicide plus herbicide to measure potential yield with maximum pest control;
2) fungicide plus herbicide to measure yield losses due to insects;
3) insecticide and fungicide to measure yield losses due to weeds;

4) insecticide plus herbicide to measure yield losses due to diseases;

5) pesticide free, to measure yield losses in the absence of a pesticide control program.

All treatments were replicated four times. Losses due to insects ranged from 42.8 to 50.3% of potential yield when no insecticides were used (Table 2). These losses were primarily due to the feeding of only one pest, i.e. potato leaf hoppers. Potatoes collapsed due to hopperburn by the first of September in all trials. These losses are approximately four times those reported in the review by Cramer (1967), although they are similar to those reported by Peterson and Granovsky (1950) and Schwartz and Klassen (1981). In these studies, losses were primarily due to the feeding of one or two species of insects, usually the Colorado potato beetle, and/or the potato leaf hopper with relatively minor losses if any due to the other insects discussed above. Thus, it is evident that in order for an integrated pest management program to be effective in Ontario, it must provide excellent control of the Colorado potato beetle and the potato leaf hopper while causing no increase in losses due to other insects.

TABLE 2. Yield Losses in Potatoes Due to Insects, Weeds and Diseases in Ontario

YEAR	SOURCE OF LOSS	PROGRAM APPLIED	YIELD tonnes/ha	YIELD $(Cdn)ha	LOSSES percent	LOSSES $(Cdn)ha
STRATHROY - mineral soil						
1981			32.98	3440.00	-	-
1982		IFH	26.43	2973.00	-	-
Mean			29.71	3206.50		
1981	INSECTS	FH	16.39	1709.00	50.3 *	1731.00
1982			15.12	1701.00	42.8 *	1272.00
Mean			15.78	1705.00	46.6	1501.50
1981	WEEDS	IF	26.34	2747.00	20.1 *	693.00
1982			22.47	2528.00	15.0	445.00
Mean			24.41	2637.50	17.6	569.00
1981	DISEASES	IH	31.12	3246.00	5.6	194.00
1982			25.32	2849.00	4.2	124.00
Mean			28.22	3047.50	4.9	159.00
1981	INSECTS,WEEDS		12.51	1305.00	62.1	2135.00
1982	DISEASES	O	8.86	997.00	66.5	1976.00
Mean			10.69	1151.00	64.3	2055.50
THEDFORD MARSH - muck soil						
1982	-	IFH	14.25	1603.00	-	-
1982	INSECTS	FH	7.29	820.00	48.9 *	783.00
1982	WEEDS	IF	4.18	470.00	70.7 *	1133.00
1982	DISEASES	IH	6.83	768.00	52.1 *	835.00
1982	INSECTS,WEEDS DISEASES	O	2.17	244.00	84.8 *	1359.00

i - contracted price $104.30/tonne (1981); $112.50/tonne (1982)

ii - loss relative to IFH program

iii - I-insecticide; F-fungicide; H-herbicide; 0-none

* - significant loss relative to IFH program in same year ($p<0.05$)

Source : Tolman et al., 1986.

2.2. DISEASES

Potatoes can be attacked by more than 50 bacterial, fungal and viral diseases including the following, late blight, early blight, verticillium wilt, fusarium wilt, bacterial ring rot, black leg, rhizoctonia, common scab, bacterial soft root, simple mosaic, rugose mosaic, leaf roll, and spindle tuber. The more significant of these diseases are discussed below.

The most significant and widespread foliar diseases in processing and table potato production in Ontario are potato early blight and late blight. Early blight survives the winter on potato debris in fields and cull piles. In the spring, spores form on the debris and are carried to new growth by wind, rain and insects. Under favorable environmental conditions, the spores germinate and the fungus penetrates the leaf tissue. Early blight is initially evident as small lesions on older leaves, close to the soil surface. The lesions expand radially to produce large corky lesions with a characteristic pattern of concentric rings. The disease spreads upward to younger leaves resulting in loss of photosynthetic ability. This may result in loss of tuber weight, and specific gravity may be reduced significantly. Generally, storage quality is not affected. The rate of development and spread of early blight is dependent on cultivar resistance and daily leafwetness periods. Infection and spread of this disease does not seem to be affected by temperature. As well as potatoes, early blight attacks tomatoes, eggplants, and related members of the nightshade family. Early blight can be of major significance to potato production in Ontario, especially to some very susceptible varieties, eg. Norchip.

While serious losses due to late blight have not occurred in the major potato growing regions of Ontario during the past 20 years, losses would occur if late blight was not controlled. The fungus survives the winter in infected tubers, either in storage or in the soil. In spring, the fungus grows vigorously in cull piles or on volunteer potato plants. When environmental conditions become favorable, usually in July, spores are blown onto the foliage of the new crop where they germinate. Other sources of infection include infected seed tubers, and spores that can be blown in from a neighboring field of infected potatoes. Brown or black spots develop on the leaves and enlarge into lesions, or dead areas, surrounded by a pale green zone that appears water-soaked. In wet weather, or in the morning while the leaves are still wet with dew, the leaf undersurface is covered by a whitish, velvet mold consisting of spores of the fungus. Disease incidence can increase rapidly due to the large reproductive potential of the asexual generations of this pathogen. Sporangia, produced from a lesion on a leaf, are transported by wind or rain drops to healthy tissue where reinfection occurs. Sporangia require water to germinate and may directly penetrate the leaf or give rise to zoospores, which subsequently germinate and penetrate leaf tissue. Late blight development and infection are favored by abundant moisture and moderate temperatures. If relative humidity is low, and leaves are not frequently wet, late blight is unlikely to develop. High temperatures, over 35° C, halt the growth of the fungus. Optimum mycelial development occurs as 23° C. Infection by late blight causes loss of photosynthetic capability which results in reduced yield.

Tubers may also become infected by late light sporangia that are washed off the leaves onto the soil. The spores penetrate the tubers through the eyes, and purplish-brown areas appear on the skin of

infected tubers. A reddish brown dry-rot develops in the flesh under these areas. The fungus does not spread from tuber to tuber in storage.

Verticillium wilt results in wilting of the leaves about flowering time, from the bottom of the plant upward. The wilted foliage becomes yellow and then brown. Severely infected plants are stunted in growth and quickly die. The organism overwinters either in debris in the soil, or in diseased tubers. The wilt usually develops from infected seed pieces or contaminated soil. The organism enters the plant through the roots and may penetrate the entire plant. Infection may spread to healthy plants through root contact. Infection results in reduced plant vitality, possibly plant death, and reduced yield.

Fusarium wilt is often confused with verticillium wilt, however fusarium wilt is usually a less important disease. Spores of fusarium wilt overwinter in potato debris in the soil, or in infected tubers in storage. During the growing season, the fungus invades the roots and spreads through the plant into tubers. In wet, cold soil this pathogen may result in rot early in the season resulting in wilt of the plant and death. In hot, dry weather, or late in the season, the rot develops slowly and there may be extensive discoloration of the stem and new tubers. Infection results in reduced quality and yield of tubers from infected plants.

Bacterial ring rot results in wilting and slight rolling of leaflets of the lower leaves usually soon after bloom. The leaflets turn pale green, and pale yellow areas develop between veins. Later, infected leaves curl at the margin and necrotic lesions appear, beginning at the bottom of the stem and spreading upwards. The infected stem wilts, turns yellow and dies. This disease develops quickly in hot, dry weather. The disease overwinters in diseased tubers and on containers and implements.

When infected seed is planted, the organism passes onto the foliage causing wilt. As the new tubers are formed, they are invaded through the stolons. This disease is highly infectious and is readily spread by potato cutters, planters, harvesters and storage containers. Infection with bacterial ring rot may result in significant losses due to tubers rotting in the field or in storage.

Blackleg is caused by a bacterium that overwinters in infected plant debris in the field or in stored tubers. This bacterium is spread at planting by contaminated implements, especially cutting knives. Bacteria may also be transferred by splashing water or by insects. Infections usually begin in the seed piece and extend upward into the stem. About flowering time, the upper leaves of one or more shoots roll upward and the foliage gradually fades from deep green to yellowish green. The plant wilts and dies as the lower stems are girdled with rot. Root maggots and nematodes may be significant in the spread of this bacterium. The disease is favored by wet soil and continuous cropping of potatoes.

Rhizoctonia (black scurf) is caused by a fungus that lives in the soil in plant debris or as "black scurf" (sclerotia) on stored potatoes. Under favorable conditions, the spores germinate and may invade plants at or below the soil line. New sprouts are readily attacked by the fungus resulting in dark-brown, dry lesions. Such lesions may girdle new shoots which restrict translocation to the developing tubers. The fungus causes dark brown lesions on roots, stolons and sprouts, and may kill part or the entire plant. This disease may result in poor seedling stand or irregular emergence of early-planted potatoes. Rhizoctonia is often more significant on red-skinned varieties. While the eating quality of the tuber is not reduced, tubers formed are often small, numerous, misshapen and covered with sclerotia.

Similar to rhizoctonia, silverscurf is common in potato growing regions in Ontario. This disease causes a discoloration of the tubers that is evident on washed potatoes, but direct losses from silverscurf are minimal.

Common scab does not affect eating quality, however, scabby potatoes are unattractive to consumers, and are wasteful due to the deep paring required to remove the scab. Severe infestations can reduce yield. This pathogen is normally present in most soils, although the use of barnyard manure favors the development of scab. The first symptoms of infestation are minute reddish brown lesions around the breathing pores of young tubers. These increase in size, turn dark, and form circular scabbed areas that are either isolated, or occur in large corky masses.

While several viruses attack potatoes, most do not affect the eating or selling qualities of potatoes for tablestock. However, the size or numbers of tubers produced is reduced. To prevent losses in tablestock production only certified seed should be planted. Thus, the control or prevention of the virus diseases is of utmost importance in the production of seed potatoes. All of the viral diseases are transmitted by insects, usually aphids, and thus control measures in seed production stress aphid control.

2.2.1. Losses Caused By Diseases

Losses due to diseases attacking potatoes can be severe. The most detailed studies concerning this relationship have been conducted on late blight (James et al. 1972; Large 1952; Mackensie and Petruszo, 1975; Latin et al. 1978).

The study by Tolman et al. (in press) in Ontario did not encounter substantial losses due to diseases when potatoes were grown on mineral soil, as environmental conditions did not favor their development (Table 2). However, potatoes grown on organic soils were in a region that had cool nights, with high humidity and heavy dews. Both late blight and early blight developed in these plots with late blight being the more significant disease. Reduced yield due to these diseases totaled 52.1% in relation to plots receiving a total pest control program.

2.3 WEEDS

The diversity of weed species that may cause significant infestations in potato fields precludes any detailed discussion of their biology. In Ontario, weeds commonly found in potato growing regions include quackgrass, foxtails, barnyard grass, smartweed, lambsquarter's, pigweed, velvet leaf and yellow nutsedge. These weeds may cause losses in terms of both reduced yield and quality. Reduced yield is a consequence of competition for water, soil nutrients and light. Quality is reduced when roots, eg. quackgrass and nutsedge, grow into and through tubers. An overabundance of weeds at harvest reduces harvest efficiency, thus increasing harvest costs. In addition, some species of weeds also serve as alternate hosts and reservoirs for insects and diseases. Severe weed infestations may interfere with the proper application of pesticides and delay drying of the field, thus promoting some foliar diseases.

2.3.1. Losses Caused By Weeds

The study by Tolman et al. (in press) indicated that reductions in yield due to weed competition were 15 - 20.1% in mineral soil, and 70.1%

in organic soil (Table 2). The most significant weeds on mineral soil were lamb's-quarters, redroot pigweed, purslane, barnyard grass, and crabgrass. The losses reported in the Tolman study were higher than those reported by Cramer (1967) although Nielson and Thorsen (1981) reported losses due to uncontrolled weeds as high as 54% in North Dokota.

2.4. NEMATODES

Potatoes are characteristically grown on light sandy soils that are ideal for the development of high nematode populations. Two nematodes, the root-knot nematode and the root-lesion nematode, attack potatoes in Ontario. Either one or both of these nematodes may be at significant levels in potato fields although usually one species dominates in a region.

The infective larvae of the root-knot nematode are ell-shaped and penetrate the roots. Once inside, the larvae swell as they mature and the root enlarges to form a gall or knot in response to the nematode. The swollen female produces several hundred eggs in a sticky mass attached to the gall. There are 2 or 3 generations per year depending on temperature. The galls interfere with the uptake of water and nutrients by the roots. This results in wilting and stunting of vegetative growth, and the formation of many small tubers rather than one normal-sized one. At high nematode infestations, the tubers have wart-like masses of tissue that render the tubers unmarketable.

The root-lesion nematode is the more important nematode in Ontario. The nematodes invade the root and start to feed. They mate, and the female lays eggs inside the root. After hatching, the larvae may move within the same root or pass through the soil into another root. Their presence in the roots causes brownish lesions which, if numerous,

destroy the normal root function resulting in wilting and stunting of vegetative growth. These wounds often act as entrances for pathogenic fungi and bacteria. Infestations by root-lesion nematodes result in reduced number and weight of marketable tubers.

2.4.1. Losses Caused By Nematodes

There are extensive data illustrating the efficacy of soil fumigants in controlling nematodes in potatoes. Results from two Canadian trials are reported in Tables 3 and 4. The work of Kimpinski (1982) showed a yield increase of about 40% in 1978 in Superior and Sebago potatoes in 1978, although there were no significant increases in yield in 1979. The most relevant study is that of Olthof (pers. comm.) that was performed in the Alliston region in Ontario. This study illustrated increases in yield of 10 - 15 tonnes/ha associated with the use of soil fumigants in severely infested soils.

TABLE 3. Influence of Soil Fumigants on Numbers of the Root Lesion Nematode in Potato Fields.

A. Source: Kimpinski, 1982 (P. E. I.)

Treatment	No. of Nematodes per kg of dry soil		No. of Nematodes per g of dry root	
1978	1 June	14 Aug.	19 Oct.	14 Aug.	19 Oct.
Untreated	6010	4100a*	5160a	4040a	3250a
Telone II (202 l/ha)	6010	1070b	3880a	1870ab	2080a
Telone II (284 l/ha)	6010	260c	3690a	1400b	1660a
1979	**30 May**	**20 Aug.**	**19 Oct.**	**20 Aug.**	**24 Sept.**
Untreated	3090	930a	6960a	1240a	4570a
Telone II (102 l/ha)	2090	240b	810b	3070a	3450a

B. Source: Olthof, (pers. comm.) (Ontario)

Treatment	Number of Pratylenchus penetrans/kg soil At Planting	At Harvest
Untreated	18320	27820a
Vorlex(55 l/ha) +Temik 10G (22 l/ha)	100	720b
Vorlex(75 l/ha)	350	10540a
Telone II(75 l/ha)	260	5540a

* Values in each column followed by the same letter are not significantly different (P=0.05) (Duncans Multiple Range Test).

TABLE 4. Influence of Soil Fumigants on Yields of Potatoes

A. Source: Kimpinski, 1982 (P. E. I.)

YEAR	Treatment(Rate)	Total Yield (tonnes/ha) Kennebec	Superior	Sebago	Russet Burbank
1978	Untreated	36.9	21.9	19.4	--
	Telone II (102 l/ha)	42.9	30.6	30.7	--
	(284 l/ha)	37.6	29.0	29.0	--
1979	Untreated	32.2	27.8	--	20.8
	Telone II (102 l/ha)	33.5	25.3	--	21.7

B. Source, Olthof, 1984. (Ontario)

Treatment	Potato Yield (tonnes/ha)
Untreated	4.7
Vorlex +Temik	20.7
Vorlex	17.3
Telone II	15.9

3. CURRENT CONTROL TACTICS USED ON POTATOES

3.1. INSECTS

The Colorado potato beetle and the potato leaf hopper are the most significant pests of tablestock potatoes in Ontario. Control measures for these pests currently rely solely upon insecticides. The insecticides recommended for use on potatoes in Ontario during the last 20 years are listed in Table 5. The currently recommended insecticides for use on potatoes and the respective target pests are listed in Table 6. Typical grower practices in the Alliston and Shelburne regions are listed in Table 7.

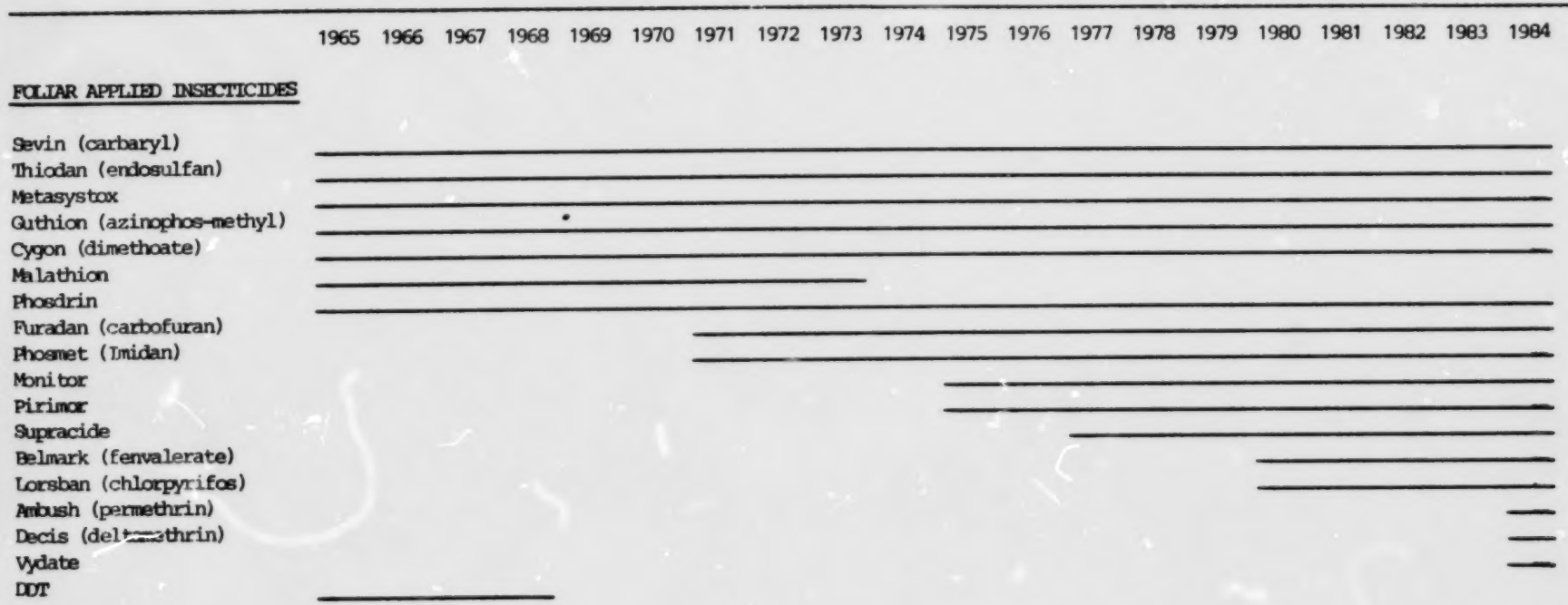
A granular insecticide is often applied at planting followed by foliar applications later in the growing season. Despite the use of a granular insecticide at seeding, some growers also apply foliar treatments early in the season if the granular insecticide is not providing the desired degree of control. Other growers do not use granular insecticides, but rather rely on a series of foliar insecticide applications for insect control. These applications are often applied on a regular basis in tank mixes with fungicides. Control measures used for the above insects often provide control of flea beetles, although in some instances an additional foliar application of insecticide may be required to control flea beetles. In tablestock production, insecticides are rarely applied specifically to control the tarnished plant bug or aphids.

The green peach aphid is primarily a pest of seed potato production due to its ability to transmit viruses. It is extremely difficult to grow potatoes for seed in commercial potato growing areas, as this aphid rarely causes loss in yield, and thus is not often controlled in tablestock production. However, even small populations of the green peach aphid can transmit viruses that result in severe problems in the

production of certified seed. Control of all aphids relies upon granular insecticides applied at planting, and/or foliar insecticide applications. In addition, seed potatoes may be topkilled when aphids carrying a virus are present, thereby preventing transmission.

Outbreaks of tuber-feeding insects tend to be sporadic, localized, and difficult to assess and treat. Cutworm control relies on granular insecticides applied at planting, weed management, and (questionably) foliar applications. Wireworm control relies on granular insecticides applied at planting, seed piece treatment, rotation out of sod, and summer cultivation. Control of seed corn maggots relies on granular insecticides applied at planting and seed piece treatment.

Table 5. Insecticides Registered and Recommended for Use in Ontario on Potatoes



Source: OMAF, Publication 363, 1985a

TABLE 6. Insecticides Currently Recommended for Insect Control on Potatoes in Ontario

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Applied At Planting To Control Aphids, Leafhoppers, And Flea Beetles:

Di-Syston 15%G or 720LC
Thimet 15%G
Furadan 10%G (also controls Col.Pot Beetle, but not aphids)
Temik 10%G (also controls Col.Pot.Beetle)

Foliar Applications To Control Potato Flea Beetles, Tarnished Plant Bugs,Potato Leafhoppers, And Colorado Potato Beetles:

Supracide 250EC
Monitor 480EC
Lorsban 4C
Guthion 240SC
Imidan 50%WP
Decis 2.5EC
Belmark 30EC
Ambush 500EC
Furadan 480F (Col. Pot. Beetle only)
Vydate L

Foliar Applications To Control Aphids:

Monitor 480EC
Pirimor 50W
Meta-Systox-R 25%
Belmark 30EC
Vydate L
Cygon 480E (potato and buckthorn aphids only)
Phosdrin (potato and buckthorn aphids only)

Foliar Applications To Control Cutworms:

Ambush 500EC

Source: OMAF, 1985a

TABLE 7. Estimated Grower Insecticide Use on Potatoes in the Alliston and Shelburne Regions of Ontario in 1984.

	PERCENT USE	
Granular*		
Temik	50	
Di-Syston	40	
Thimet	10	
Foliar	**With Granular****	**No Granular*****
Furadan	10	10
Lorsban	30	20
Decis	7	7
Pirimor	2	2
Supracide	30	34
Belmark	14	20
Monitor	5	5
Meta-Systox	2	2

* 75 percent of growers in the region use granular insecticides

** If a granular is applied, the average grower uses an additional 2 foliar applications per year.

*** If a granular is not applied, the average grower uses 5 foliar applications per year.

3.2. DISEASES

Current recommendations for the control of late blight suggest the use of sanitation and destruction or burying of cull piles and crop residues as cultural control measures. In addition, it is recommended that potato cultivars should be chosen that display tolerance or resistance to early and late blight. However, the intensive use of fungicides is relied upon to provide most of the control required. Fungicide applications are usually initiated in late June or early July when the crop is about 20 cm high, especially when cool moist conditions are prevalent. During continuous moist weather, intervals between spray applications should not exceed 7 days. In warm dry conditions, this interval may be lengthened to 14 days. If tubers are a marketable size and late blight is present in the field, it is recommended that a top killer be applied to prevent tuber infection. This organism has shown the potential to develop resistance to some fungicides very rapidly, and thus it is not preferable to rely upon the intensive use of fungicides for control.

The fungicides recommended for control of early and late blight in Ontario during the past 20 years are listed in Table 8. The fungicides currently recommended for early and late blight control are listed in Table 9. The average fungicide program for a grower in the Alliston and Shelburne regions is illustrated in Table 10. The cultivars of potatoes commonly grown in Ontario and their sensitivity/tolerance to some diseases is listed in Table 11. The cultivars Norchip and Superior are especially susceptible to early blight, and control measures are usually initiated early in the season on these varieties. In varieties other than Norchip and Superior, the control measures used for late blight will usually provide adequate control of early blight.

Table 8. Fungicides Registered and Recommended for Use on Potatoes in Ontario

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
SEED TREATMENTS																				
Captan/Diazinon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Polyram/Diazinon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Easout																				
Gypsum																				
Semesan Blue	—	—	—	—	—	—														
FOLIAR APPLIED FUNGICIDES																				
Polyram (metiram)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maneb	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dithane-45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nabam/Zinc Sulfate	—	—	—	—	—	—	—													
Difolatan (captafol)							—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bravo (chlorothalonil)								—	—	—	—	—	—	—	—	—	—	—	—	—
Du-ter (fentinhydroxide)														—	—	—	—	—	—	
Ridomil/MZ (metalaxyl and maneb)																				—

Source: OMAF, Publication 363, 1985a

TABLE 9. Currently Recommended Fungicides for the Control of Foliar Diseases on Potatoes.

Foliar Applications For The Control Of Early and Late Blight:
Maneb 80%WP
Dithane M-45 or Manzate-200
Polyram 80W
Difolatan 480F
Bravo 500
Ridomil/MZ late blight only

Source: OMAF, 1985a

TABLE 10. Estimated Grower Fungicide Use on Potatoes in the Alliston and Shelburne Regions of Ontario in 1984.

	PERCENT USE
Seed Treatment*	
Polyram	5
Easout	45
Gypsum	45
Foliar Fungicides**	
Polyram	4
Dithane 45	29
Difolatan	10
Bravo	53
Ridomil/MZ	4

* as used on cut seed pieces; 5% of growers apply no seed treatment to cut seed; no seed treatment is used on whole seed.

** potato growers in this region typically use 4 - 7 foliar fungicide applications per season with early potatoes using few applications and late susceptible varieties with most applications; average use is 5 per season.

TABLE 11. Cultivar Sensitivity/Tolerance to Selected Diseases of Potatoes Commonly Grown in Ontario.

Jemseg:	immune to virus X, resistant to common scab and to viruses Y and S; susceptible to virus leafroll, Verticillium wilt and Fusarium storage rot.
Superior:	scab resistant but susceptible to Verticillium wilt at maturity.
Yukon Gold:	moderately susceptible to common scab and virus Y; resistant to mild mosaic and moderately resistant to virus leaf roll.
Conestoga:	moderately resistant to virus leaf roll, net necrosis early blight and common scab; moderately susceptible to mild and rugose mosaic.
Simcoe:	resistant to mild mosaic and late blight; moderately resistant to common scab; moderately susceptible to Rhizoctonia; susceptible to virus leaf roll.
Keswick:	scab and late blight resistant.
Norchip:	susceptible to early and late blights, Verticillium wilt, silver scurf and spindle tuber.
Chieftan:	susceptible to Verticillium wilt, spindle-tuber and silver scurf; resistant to scab, mild mosaic net necrosis and late blight.
Trent:	moderately susceptible to scab and late blight; susceptible to most mosaic-type viruses.
Kennebec:	late blight resistant; scab tolerant; very susceptible to Verticillium wilt.
Rideau:	very resistant to Verticillium wilt; moderately resistant to common scab, mild mosaic, rugose mosaic, and virus leaf roll; moderately susceptible to Rhizoctonia.
Shepody:	resistant to early blight; moderately resistant to Rhizoctonia, Phoma, and Fusarium storage rots; susceptible to common scab, Verticillium wilt, late blight and virus Y.
Nipigon:	moderately resistant to scab and the mosaic viruses; resistant to black leg and late blight.
Russet Burbank (Netted Gem)	scab-resistant; susceptible to most viruses, late blight and Verticillium wilt.
Sebago:	scab and late blight resistant; very susceptible to black leg.

Source: OMAF, 1985a.

Control recommendations for bacterial ring rot, blackleg, verticillium and fusarium wilt, silver scurf, and rhizoctonia focus on the use of cultural control methods and, for some of these diseases, seed treatments. The use of crop rotation using non-host crops is strongly recommended to reduce the build up of these diseases in soils. For the control of black ring rot and blackleg, careful sanitation is recommended including the use of disinfectants (eg. King Anti-Ring Rot Disinfectant, Niagara HY-X Disinfectant) on cutting knives and planters. All cull potatoes should be spread evenly on the field to freeze or cull piles buried. The use of Plant Foundation or Certified seed is also strongly recommended to reduce losses from viruses, bacterial ring rot, black leg, Verticillium wilt, Rhizoctonia and common scab. All seed should be thoroughly inspected and any seed pieces or tubers showing rot should be discarded. Lower pH values also provide better control of common scab. To reduce pH, applications of limestone are recommended.

In addition to the above, seed treatments can be used to reduce losses due to soil borne pathogens (eg. Verticillium wilt) and some insects including wireworms and seed maggots. A listing of seed treatments that have been used during the past 20 years is included in Table 8. The currently recommended seed treatments are Polyram-diazinon dust, Captan 7%-diazinon 0.1% dust, Easout Potato Seed Piece Treatment and Gypsum. An estimate of current grower use of seed treatments in the Alliston and Shelburne regions is listed in Table 10. In severely infested fields, seed treatments will not provide adequate control and long term crop rotation is strongly recommended.

Control of viruses is of much greater importance to seed growers than to tablestock producers. The primary means of control used by tablestock producers is to use certified seed and to a lesser extent, control aphid populations. To produce certified virus-free seed,

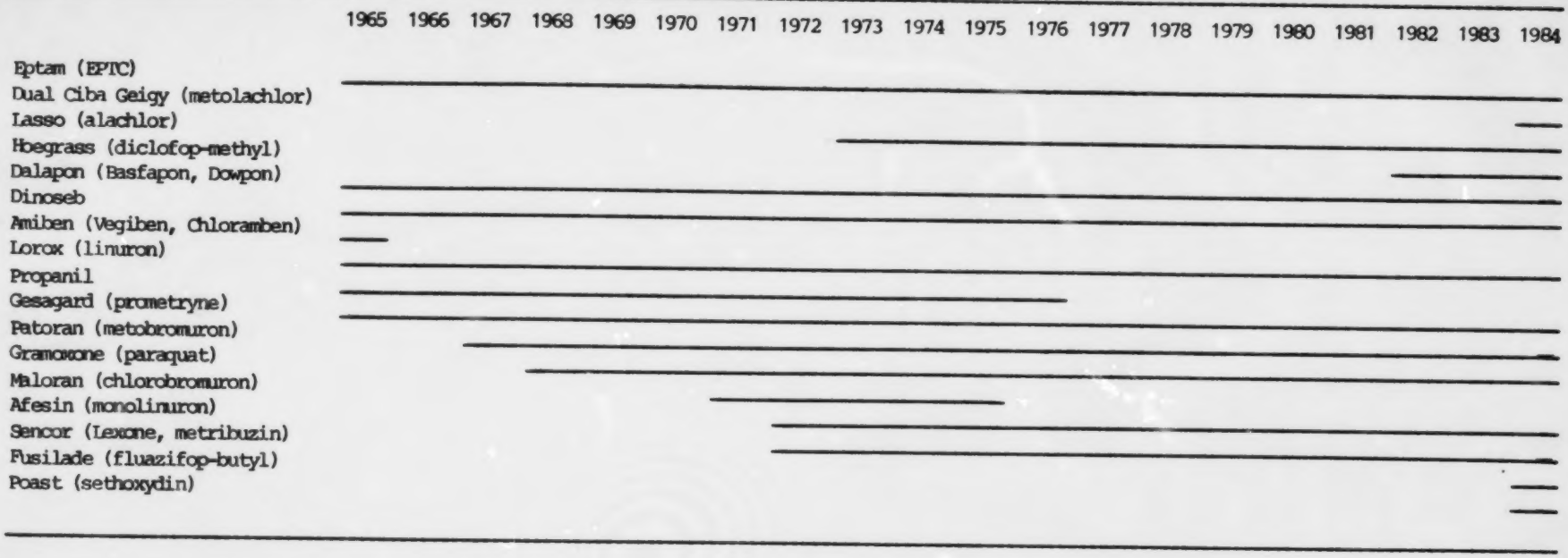
growers must ensure excellent aphid control, usually with the use of both systemic granular and foliar insecticide applications. All plants that show symptoms of infections are rogued, and top killer applied to prevent late virus transmission. If at all possible seed fields should be isolated from non-certified potatoes.

3.3. WEEDS

Weed control in potatoes is based upon the use of herbicides, although some control of "escapes" is achieved by hilling. Hilling may be performed as the final cultivation to smother small weeds and to provide a suitable volume of well-aerated soil in which tubers can grow and be protected from greening (sunburn) and frost. However, the hilling process may result in the production of more weeds as untreated soil is brought to the surface. The use of a herbicide after hilling may be required. Under most conditions in Ontario, cultivation with a harrow or finger-weeder will provide sufficient control of seedling annual weeds between planting and first hilling. If weed cover is light, cultivation at first hilling may be all that is necessary. Pre-emergence herbicides are often used soon after first hilling until the crop emerges. Post-emergence treatments are used to control germinating seedlings and weeds growing between rows.

A wide variety of herbicides are available for use in potatoes in relation to other horticultural crops. Registered materials, when applied at the proper time, provide excellent control of weeds. The herbicides that have been recommended for use in potatoes during the past 20 years are listed in Table 12. The herbicides currently recommended for use on potatoes in Ontario and their target weeds are listed in Table 13. A typical potato grower in the Alliston region uses two applications of herbicides per year, the most commonly used products are indicated in Table 14.

Table 12. Herbicides Registered and Recommended for Use on Potatoes in Ontario



Source: OMAF, Publication 75, 1985b.

TABLE 13. Currently Recommended Herbicides for Use on Potatoes in Ontario.

PREPLANT INCORPORATED HERBICIDES	
Germinating annual grasses	EPTC EPTAM
Germinating annual grasses and broadleaf weeds	EPTC EPTAM plus metribuzin (SENCOR, LEXONE)
Nutsedge	EPTC EPTAM
Quackgrass	dalapon (DALAPON, DOWPON, BASFAPON)
PREEMERGENCE OR AT EMERGENCE HERBICIDES	
Germinating annuals	alachlor (LASSO) tank mixed with one of: dinoseb (DINITRO) or linuron (LOROX, AFOLAN) or metribuzin (LEXONE, SENCOR) (Please note that alachlor cannot be used on potatoes as of 1985) dinoseb (AMINE DINITRO) metoalachlor (DUAL) tank mixed with one of: metobromuron (PATORAN) or monolinuron (AFESIN) or metribuzin (SENCOR, LEXONE) linuron (LOROX, AFOLAN) monolinuron (AFESIN) metribuzin (SENCOR, LEXONE) metribuzin (SENCOR) plus dalapon (DALAPON, DOWPON, BASFAPON) prometryne (GESAGARD)
EMERGED WEEDS	paraquat (GRAMOXONE)
POST EMERGENCE HERBICIDES	
Late germinating grasses	EPTC EPTAM
Annual grasses, wild oats and volunteer corn	diclofop-methyl (HOE-GRASS)
Emerged quackgrass and annual grasses	fluazifop-butyl (FUSILADE) sethoxydin (POAST) (new registration)
Emerged annual weeds	metribuzin (SENCOR, LEXONE)

The above list does not include all split applications, nor does it include limitations of use and warnings. Lower case names are common names, upper case names are trade names.

Source: OMAF, 1985b.

TABLE 14. Estimated Herbicide Use by Potato Growers in the Alliston and Shelburne Regions of Ontario in 1984.

	PERCENT USE WITHIN EACH GROUP
Preemergence Annual Grass	
EPTAM (EPTC)	40
DUAL	60
Postemergence Grass	
Fusilade (annual)	10
Poast (annual)*	90
Poast (perennial)*	40
Fusilade (perennial)	60
Broadleaf Herbicides	
Linuron	30
Afesin	30
Sencor/Lexone	30
Other	10

* new registration

Approximately 45 percent of potato hectares are treated with only a broad leaf herbicide. Approximately 30 percent of potato hectares are treated with a broad leaf herbicide and DUAL or EPTAM. Approximately 23 percent of potato hectares are treated with a broad leaf herbicide and Poast or Fusilade. Approximately 2 percent of potato hectares are treated with a broad leaf herbicide and Dual or Eptam and Poast or Fusilade.

3.4 NEMATODES

Losses in potatoes due to the nematodes found in Ontario are usually not spectacular, and are often difficult to recognize. As a result of the low unit value of potatoes, the high cost of soil fumigants, the perception that nematodes are not causing significant losses, and logistical problems with the use of economic thresholds, soil fumigants are rarely used in this crop. Some growers rely upon crop rotation to reduce populations of the root knot and root lesion nematodes, however almost all vegetable and field crops are hosts for either one or both of these nematodes. Some growers currently rely upon the use of aldicarb, that is used for insect control, to provide some control of the nematodes.

The soil fumigants recommended for use for nematode control in potato fields in Ontario are Telone II and Vorlex. There are estimated to be less than 40 hectares of potatoes treated each year with soil fumigants. When soil fumigants are used, the treatment is usually done in the fall prior to planting. The fumigants are applied as broadcast or row treatments, the latter being preferred due to lower costs. Spring application is not usually used, as it may result in significant delays in planting.

4. PROBLEMS ASSOCIATED WITH CURRENT CONTROL TACTICS USED ON POTATOES

4.1 PESTICIDE RESISTANCE

The development of resistance to a pesticide is an evolutionary process in which repeated exposure of a population to the pesticide gradually eliminates those members that are not capable of tolerating the usual dose of the pesticide. This occurs repeatedly, so that over time the population consists primarily of individuals that are practically immune to the action of the pesticide. The development of pesticide resistance by insects and pathogens that attack potatoes is well documented, and presents a serious problem.

Resistance of the Colorado potato beetle to synthetic organic insecticides was first noted with DDT in New York State in 1952. Since that time, populations of the Colorado potato beetle in New York, Long Island, and New Jersey have developed resistance to almost all insecticides registered for its control in the United States. For example, in Rhode Island the only effective foliar applied insecticides are synergized pyrethrins and rotenone. Growers in that region are relying on these insecticides, the antifeeding properties of some fungicides, and insecticidal action of some herbicides to provide control of the Colorado potato beetle.

In Ontario, no resistance to DDT or other chlorinated hydrocarbon insecticides was evident for many years (Founk and McClanahan, 1970). More recently, populations of Colorado potato beetles in Ontario have developed resistance to a variety of chlorinated hydrocarbon insecticides, including DDT (Harris and Svec, 1976). In addition, there are indications that the development of resistance to organophosphates and carbamates has

started (Table 15). At present, levels of resistance are low and current application rates will probably provide an acceptable level of control. However, with the presence of resistant individuals in the populations, the continued intensive use of these insecticides will result in the rapid development of resistance as has occurred in other regions, eg. Sherbrooke, Quebec (Harris et al. 1982). Where possible, strategies should be developed and implemented that delay the development of pesticide resistance. This is the subject of active research by C.R. Harris, Agriculture Canada Research Station, London. Levels of resistance should be monitored to prevent or reduce possible losses if resistance was to develop rapidly.

TABLE 15. Direct Contact Toxicity of Three Insecticides to Three Strains of Colorado Potato Beetle from Southwestern Ontario in 1980.

INSECTICIDE	STRAIN	AVG. CORRECTED % MORTALITY AT % INSECTICIDE SOLUTION INDICATED			
		0.001	0.01	0.1	1.0
Azinophosmethyl	London	0	5	100	100
	Alliston	0	0	74	100
	Leamington	0	0	88	100
Phosmet	London	5	10	95	100
	Alliston	0	0	10	100
	Leamington	3	10	8	93
Carbofuran	London	0	85	100	100
	Alliston	5	75	100	100
	Leamington	0	73	90	95

Source: Harris et al., 1982.

Some of the major pathogens that attack potatoes have also developed resistance. Resistance has not developed rapidly to the protectant fungicides, probably due to their nonspecific mode of action that interferes with many vital functions of the fungi. However, the

development of resistance by late blight to the very effective and specific, eradicant fungicides has occurred rapidly in other parts of the world (Davidse et al., 1983). Resistance has not yet been reported in Ontario. As suggested with the use of insecticides, a strategy should be developed in relation to fungicide use that would delay and monitor the development of resistance.

4.2 GROUND WATER CONTAMINATION WITH PESTICIDES

In recent years there has been considerable concern about the contamination of ground water supplies with pesticides. This is of primary consideration in potato production, as potatoes are typically grown on light, sandy soils in which the vertical movement of water-soluble compounds is relatively rapid and extensive. In some potato growing regions in the United States, ground water contamination by pesticides (insecticides and herbicides) has been reported.

Since 1979, aldicarb has been found to be a ground water contaminant where potatoes are grown in a number of cases in the northeastern United States. In this region, aldicarb has been used at high application rates for the control of root knot and root lesion nematodes, and at lower rates for the control of insects. As a result of ground water contamination, the use of this product for the control of nematodes has been removed from the label, and aldicarb can only be used every second year for the control of insects. This is of considerable concern to potato growers, as in many potato growing regions of the northeastern United States, aldicarb is the only registered material to which Colorado beetle has not developed resistance.

4.3 COSTS OF PEST CONTROL

Pest control costs are a significant component of potato production costs. The real costs (corrected for inflation) of insect control on potatoes in Ontario have steadily increased during the past ten years, (Figure 1). This is in contrast to real cost decreases which have occurred on onions and apples, commodities on which IPM programs have been implemented in Ontario.

Total pesticide expenditures on potatoes in Ontario are compared to other crops and regions in Canada, Michigan and New York State in Tables 16 and 17. It is evident that total pesticide expenditure on potatoes in Ontario are higher than in Quebec and the Maritimes, yet slightly lower than in B.C. On a commodity basis, only pesticide expenditures in apple production are greater than those of potatoes, in Canada. All other crops selected for comparative review, (strawberries, grain corn, soybeans, tobacco, and field tomatoes) have lower pesticide expenditures, which account for smaller shares of total costs of production, compared to potatoes or apples.

In Michigan, potato pesticide expenditures are a fraction of expenditures in New York or Canada, accounting for only 7% of total costs of production, compared to 21% in New York and 13% in Ontario. Reductions in pest control costs would allow Ontario grown potatoes to be more competitive in international markets.

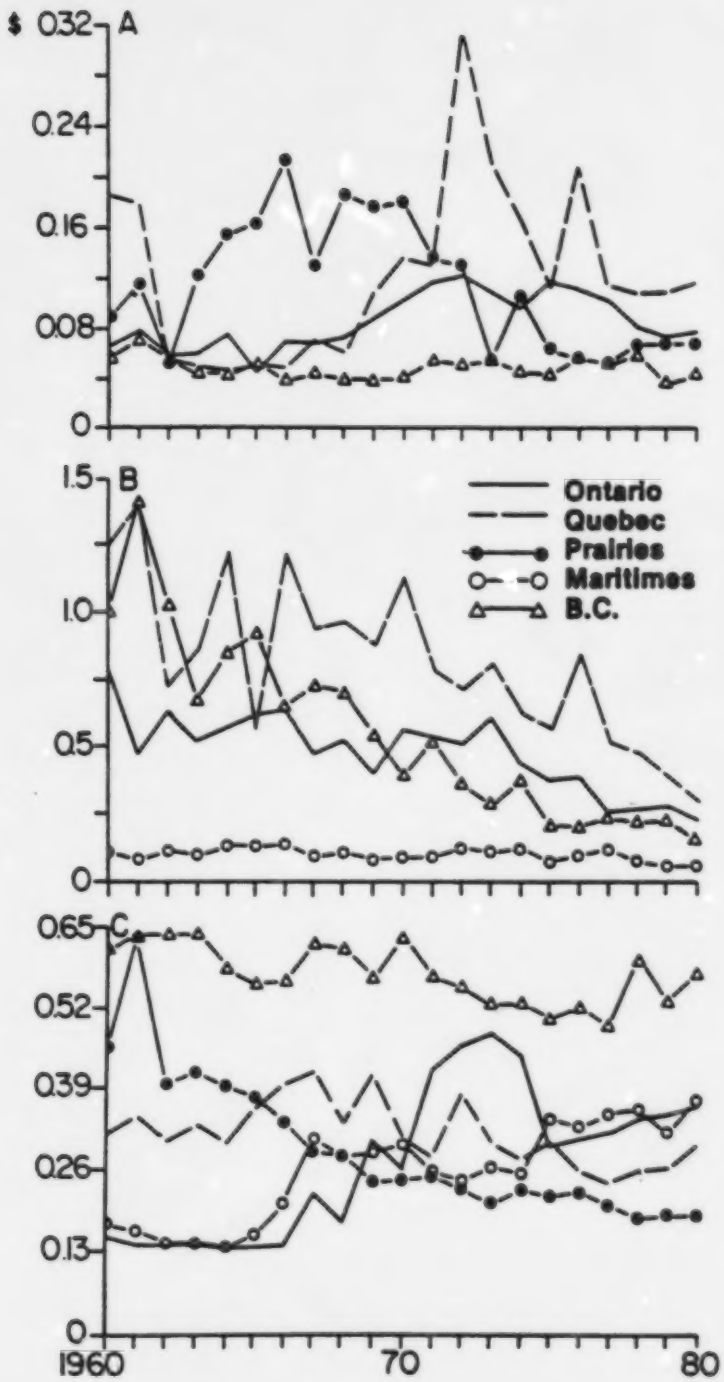


Figure 1: **Insecticide Cost per Bushel in A-Onions, B-Apples and C-Potatoes.**

Source: Stemeroff and George, 1983.

Table 16. Pesticide Costs ($US/hectare) in Michigan and New York State

	Michigan			New York		
Crop	Pesticide cost/ha	% TVC	%TC	Pesticide cost/ha	%TVC	%TC
Apples	768 (1)	25	13	590 (2)	17	13
Potatoes	150 (3)	N.A	7	310 (4)	25	21
Strawberries	525 (5)	6	4	300 (6)	N.A	N.A
Grain Corn	82 (7)	N.A	5	70 (8)	12	9

1. Kelsey and Bradford, 1985b
2. Snyder, 1984a
3. Greenburg et al., 1983
4. Snyder, 1982
5. Kelsey and Bradford, 1985a
6. Search et al., 1984
7. Hamilton, 1983
8. Snyder, 1984b

TVC = total variable cost
TC = total cost
N.A = data not available

Table 17. Total Pesticide Costs (per hectare) for Selected Crops in Canada ($ CAN)

Crop	B.C.			Ontario			Quebec			Maritimes		
	Pesticide cost/ha	% TVC	% TC	Pesticide cost/ha	% TVC	% TC	Pesticide Cost/ha	% TVC	% TC	Pesticide cost/ha	% TVC	% TC
Apples	463 (B.C.M.A.F., 1984)	12	8	655 (McKibbon, 1983)	19	15	530 (M.A.P.A.Q., 1983b)	23	18	300 (Lemoine, 1982)	14	12
Potatoes	434 (B.C. Crop Ins., 1983)	14	8	400 (O.M.A.F., 1984)	20	13	250 (M.A.P.A.Q., 1983c)	14	10	285 (RD&IA, P.E.I. Dept. Ag., 1984)	11	9
Strawberries	478 (B.C. Crop Inc., 1984)	9	6	350 (Buth and McKibbon, 1984)	6	5	369 (M.A.P.A.Q., 1982)	15	10	613 (Hagarty, 1984)	10	6
Grain Corn	N.A	N.A	N.A	70 (O.M.A.F., 1984)	14	8	55 (M.A.P.A.Q., 1983a)	7	5	N.A	N.A	N.A
Soybeans	N/A	N/A	N/A	69 (O.M.A.F., 1984)	24	10	N/A	N/A	N/A	N/A	N/A	N/A
Tobacco	N/A	N/A	N/A	440 (Fisher, 1983a)	9	6	250 (M.A.P.A.Q., 1983d)	6	4	40 (Andrew, 1984)	2	1.5
Tomatoes (Field)	80 (B.C.M.A.F., 1981)	2	1.5	190 (Fisher, 1983b)	2	1.5	200 (M.A.P.A.Q., 1983e)	7	N/A	N/A	N/A	N/A

N/A = not applicable
N.A = data not available
TVC = Total variable cost
TC = Total cost

5.0 POTENTIAL TECHNIQUES FOR USE IN INTEGRATED PEST MANAGEMENT ON POTATOES

It is evident from the above discussion that a variety of pesticide and other control tactics are available for use in the control of pests on potatoes. This section will describe means of optimizing the use of pesticides and currently available alternatives, so as to minimize the problems associated with current control practices. It will also provide a brief discussion of some of the potential control tactics that may be available for use in an IPM system on potatoes in the near future.

5.1 INSECTS

5.1.1 Pest Monitoring Techniques and Economic Thresholds

A variety of studies has investigated the effects of defoliation of potatoes on yield. These studies have used simulated defoliation (Sparks and Woodbury, 1967; Cranshaw and Radcliffe, 1980; Shields and Wyman, 1984; Wellik et al., 1981) or defoliation caused by Colorado potato beetles (Hare, 1980; Logan, 1981; Ferro et al., 1983) to correlate damage and yield. These studies have shown that the potato plant is most susceptible to defoliation between 50 and 100% bloom, with defoliation early and late in the growing season having little effect on yield. These findings, in conjunction with daily feeding rates of defoliating insects, will provide the basis for the development of simple economic thresholds for defoliating insects that attack potatoes. Unfortunately, published thresholds are not currently available, primarily due to the complexity of factors influencing defoliation, and the variable response of potato yield

to a given level of defoliation. The most significant factors that influence this relationship are: difference in varietal response to defoliation, and the effects of environmental differences that alter the biology of the plant and the insects. The influence of these factors is under study and initial models that predict population dynamics of the Colorado potato beetle, the resulting defoliation, and yield loss are under development (Logan, 1981). Despite the lack of complete data, some nominal thresholds have been developed and used as tentative guidelines for IPM on potatoes.

Pest monitoring methods developed for insects on potatoes have focused on the scouting of fields and through direct observation, counting the number of Colorado potato beetles, potato leaf hoppers, or aphids on a portion of, or on entire plants. No threshold levels for flea beetles attacking potatoes could be found in the literature nor, to the knowledge of the authors, are they currently in use in other potato growing regions. Currently used scouting procedures for the Colorado potato beetle recommended by extension programs in Rhode Island and Long Island (Moyer, 1984) are as follows:

Commencing with the emergence of the plants in the spring, weekly observations should be made in each field. At least 10 sites should be chosen in the field to make observations (fields larger than 20 ha should be checked at 15 sites). Sites should not be near the edge of the field to avoid border effects. Sites should be chosen while walking through the field on a V- or W-shaped path. At each site, five plants should be inspected and the number of adult Colorado potato beetles counted. Early in the growing season (before Colorado potato beetle eggs hatch), if adult beetles are found at a density of 1 or more per plant, the entire field should be sprayed. If pockets of high populations are found near the

borders, near hedgerows, or in other protected areas, only the areas with high populations should be treated.

After Colorado potato beetle eggs hatch in late May and in June, larvae and adults must be counted. At each site (at least 10 sites per field), one potato stalk (vine) from each of five different plants is inspected and the number of larvae and adults present counted. Separate counts should be made of small (less than half grown) and large (greater than half grown) larvae. At each site, an estimation of percent leaf loss (defoliation) should be made. The data should then be compared to Table 18.

TABLE 18. Colorado Potato Beetle Spray Guidelines as used in Rhode Island and Long Island, U.S.A.

CPB STAGE	CPB/50 VINES	
	HIGH	LOW
Adults	25% or greater	15 or less
Small Larvae	200 or greater	75 or less
Large Larvae	75 or greater	30 or less

Source: Moyer, D.D.

If the number of beetles found is in the high category for any stage an insecticide should be applied very soon. If the numbers found are less than the low guidelines, no insecticide should be applied that week. If the numbers found are between the high and low ranking, no insecticide is needed now, however, the field should be checked again in 3 to 5 days.

In addition to monitoring populations of Colorado potato beetles, information concerning defoliation levels can also be used to determine the potential for significant damage. Defoliation below 20%, even at the most sensitive stage of tuber formation and bulking, rarely causes significant yield loss.

A substantial amount of information is available concerning the effect of hopper burn on potatoes and the relationship between hopper burn and yield. Observations of injury to potatoes caused by the potato leaf hopper indicate a linear relationship between nymph populations and percent hopper burn. The relationships between yield, percent hopper burn and potato leaf hopper density were approximated by logarithmic curves. Relatively large reductions in yield were caused by low leaf hopper populations. With further increases in leaf hopper populations yield losses were not proportionally as large (Peterson and Granovsky, 1950). In some situations, most of the hopper burn has been associated with nymphal populations only (Sanford and Webb, 1977). As seen with defoliation, the effects of hopper burn are most significant when rapid tuber bulking is occurring (Cancelado and Radcliffe, 1979a).

Two published economic thresholds are available for potato leaf hoppers attacking potatoes. Cancelado and Radcliffe (1979a) in Minnesota, developed a threshold base on nymphal populations of the potato leaf hopper. The threshold was ca. 10 nymphs/105 mid-plant leaves. The number of samples for use of this threshold in commercial fields was not indicated although counts were made once each week.

Walgenbach and Wyman (1984) developed a dynamic threshold for potato leaf hoppers in Winsconsin that was based on both adult and nymphal population densities. The sampling method requires 1) the use of a 38 cm diameter sweep net to provide an estimate of adult populations, and 2) counts of the number of nymphs on leaves from the middle of the plant to provide an estimate of nymphal populations. The regression equation produced from their experiments was $y=400-16x$, with an x intercept of 25 nymphs per 25 leaves. Rearrangement of the regression model produces:

$$\frac{Y}{(25 - X)} = 16$$

y = adults/25 sweeps

x = nymphs per 25 leaves

If, after substituting the observed x and y values, a resultant value is greater than 16, yields may be reduced if populations are not controlled. A value of less than 16 indicates that populations are not sufficient to affect yield significantly. This paper does not indicate the number of samples required for use of this threshold in commercial fields, although samples were taken each week.

Historically, the green peach aphid has not been a significant problem in tablestock production in Ontario. However, its ability to increase rapidly to high population levels, and develop resistance to insecticides, requires that a constant vigil be maintained on this species. An economic threshold for the green peach aphid has been developed for tablestock potatoes grown in Minnesota. Cancelado and Radcliffe (1979b) have shown that a population level in excess of ca. 30 apterae/105 leaves will cause significant losses. The threshold used in seed production is considerably lower, i.e. ca. 10/105 leaves, with the assumption that a systemic insecticide, preferably aldicarb, was applied at planting. The number of samples required in commercial fields was not indicated, however, sampling was done once each week.

In addition to the above threshold, a computerized model known as GPA CAST has been developed (Smilowitz, 1981). This program uses population monitoring of the green peach aphid and its natural enemies, weather information, and plant growth to predict populations of the green peach aphid. It also calculates whether or not the population has, or will exceed the economic threshold. This program is complex and will not be described in detail herein.

To the knowledge of the authors, none of the thresholds discussed above has been tested in commercial potato production in Canada. Therefore, their applicability for use in Ontario, even as nominal thresholds, must be carefully evaluated.

5.1.2 Potential Control Measures

Biocontrol Agents

At the current time, biological control of the Colorado potato beetle is ineffective in the major potato growing regions of the United States and Canada (Harcourt, 1971; Tamaki and Butt, 1978). Numerous native parasites and predators of the Colorado potato beetle have been studied for their potential for use as biocontrol agents. Studies have included the use of inundative releases; habitant modification to increase the effectiveness of native predators and parasites; and modfication of pesticide use to reduce deleterious effects on significant predators and parasites. Native predators or parasites of the Colorado potato beetle that have received study include Persillus bioculatus (Tamaki and Butt, 1978), Podisus maculiventris and Doryphorophaga doryphorae (Tamaki et al., 1983a, 1983b). While these and other species of predators and parasites may be present in potato fields, they usually do not have significant effects on populations of the Colorado potato beetle.

Studies in New Brunswick have indicated that the insect community in potato fields is simple and depauperate. While predators and parasites are present, they do not result in significant reductions of insect populations in most instances (Boiteau, 1983, 1984). Within the range of current agronomic practices, changes in row spacing or changes in the acceptable level of weed control had little or no effect on arthropods in potato fields in New Brunswick. When row spacing was altered in early

planted potatoes, a trend towards increased populations of carabids resulted, however, carabids were found to be highly susceptible to herbicide applications. Altering the use of herbicides and insecticides may result in increased effectiveness of parasites (Tamaki et al. 1984), although this has not been tested in commercial field conditions.

Exotic parasites of the Colorado potato beetle were recently found in Mexico and Columbia. Research on the potential of the parasitic wasp, Edovum puttleri, as a control agent for the Colorado potato beetle is currently being conducted in the northeastern United States (Beltsville, Maryland; Rutgers Univ. New Jersey) and in Ontario (M.K. Sears, Univ. of Guelph). This species is an egg parasite that can be laboratory reared. However, this species cannot overwinter in Canada, necessitating the use of inundative releases of this insect. Unless rearing costs can be substantially reduced, the use of this parasite in commercial potato production is not likely. Recent studies on the parasitic mite Chrysomelobia labidomerae provided mixed results (Eickwort, 1975), and success in the near future is unlikely.

The use of native pathogens for the control of the Colorado potato beetle has been discussed by Roberts et al. (1981). None of these agents has had significant effects on populations of the Colorado potato beetle. Modification of the environment (row spacing, weed control) within acceptable limits, did not increase the incidence of native entomophthoran fungi in potato fields in New Brunswick. However, the inundative release of the fungal pathogen Beauveria bassiana did show some promise for Colorado potato beetle control. Field tests have indicated that foliage protection can be obtained with the application of this pathogen (Fargues et al., 1980). However, much work must be done with this pathogen, (formulation, application, production, effects on nontarget organisms

including man, characterization of virulence of the many strains of this pathogen, etc.), before it can be of use in commercial potato production (Roberts et al. 1981). Research is currently ongoing in this area by both private industry and government funded research establishments in the United States and Europe. There may also be potential for the use of an exotoxin produced by strains of Bacillus thuringiensis for the control of the Colorado potato beetle.

Native predators and parasites of the aphids attacking potatoes, especially the green peach aphid, have been studied in some detail (Ben Saad and Bishop, 1975; Shands et al. 1972; 1975). A large variety of predators and parasites attack aphids in potato fields, and parasites of the green peach aphid have been shown to cause significant effects on populations of this aphid (Tamaki, 1981; Smilowitz, 1981). Soper (1981) has shown that there is a variety of pathogens that attack aphids in potato fields and they exert a significant effect on aphid population dynamics. Current research is investigating the economic mass production of entomophthorales for the control of the potato aphid. This research is also designed to compare the commercial competitiveness of these fungi with conventional insecticides and develop the information required for registration of these fungi as pest control agents in the United States (Soper, 1981).

Aphids rarely become a problem in tablestock production in Ontario, probably because of the combined effects of native natural enemies and the activity of insecticides primarily applied for the control of other insects, eg. aldicarb. The reduction in use of insecticides for the control of other insect species on potatoes that may result from the implementation of an IPM program, could result in changes in aphid populations. Therefore, populations of aphids would have to be closely monitored as part of an IPM system.

5.1.3 Host Plant Resistance

Tuber-bearing species of the genus Solanum have been extensively assessed for arthropod resistance over the past forty years (Tingey, 1981). Much of this work has focussed on resistance to the Colorado potato beetle, the potato leaf hopper and the green peach aphid. Generally, potato cultivars currently commercially grown are uniformly susceptible to attack by the Colorado potato beetle, although some do differ in their ability to tolerate and compensate for defoliation (Schalk et al., 1975). The greatest levels of resistance are present in wild species of Solanum. Host plant resistance to the attack of the Colorado potato beetle has been associated with the total and individual glycoalkaloid composition of potato foliage (Tingey, 1981; Sinden et al., 1978, 1980; Tingey et al. 1978). Chemosensilla have been identified on the tarsi of Leptinotarsa that are specific to inhibitory materials (alkaloids) that occur in unacceptable plants. In addition, the maxilla contain receptors sensitive to feeding of stimulants (Mitchel and Schoonhoven, 1974). Certain solanaceous glycoalkaloids (tomatoes, chaconine, commersonine, demissine, leptines) have been shown to deter the feeding of the Colorado potato beetle (Gregory et al. 1981; Hsiao and Frankel, 1968; Schreiber, 1957; Sinden et al., 1980; Struchow and Low, 1961).

Resistance of potatoes to a variety of arthropods has also been shown to be associated with the presence of various glandular trichomes (Gibson, 1978; Tingey, 1981). Phenolic compounds in the tips of glandular trichomes of potato entrap insects including the green peach aphid, potato aphid and the Colorado potato beetle (Gibson and Turner, 1977; Stoner et al., 1968; Ryan et al., 1982). Upon contact, these trichomes discharge a viscous exudate that accumulates on the insect's body leading to mechanical entrapment. This usually results in death of the insect within

several days of confinement. Terpenoids in glandular trichomes may also be toxic to some insects (Kennedy and Yamamoto, 1979).

Cultivars of potatoes vary substantially in their infestation and yield response to the potato leaf hopper (Tingey, 1981; Sanford and Webb, 1977). However, the cultivar Sequoia is the only named potato variety for which resistance against the potato leaf hopper is considered to be a major feature. A wide variety of resistance levels to potato leaf hoppers is present in wild Solanum species. Resistance has been associated with two mechanisms, namely glandular trichomes and leaf glycoalkaloid content (Tingey, 1981; Dahlman and Hibbs, 1967; Tingey et al. 1978).

Resistance against aphids does vary in cultivars of potatoes commercially grown and often fluctuates with stage of plant growth. There is considerable genetic diversity for aphid resistance in wild Solanum species. Some progress has been reported in transferring resistance to aphids between wild species and S. tuberosum that has been associated with glandular pubescence.

Despite considerable progress in the identification of potential sources of resistance against insects in potatoes, there is relatively little known about inheritance mechanisms of that resistance. Despite this, leaf glycoalkaloid content of potatoes has been manipulated by breeding to provide excellent levels of protection against the Colorado potato beetle and potato leaf hopper. However, there is a strong correlation of the broadly toxic glycoalkaloids in the leaves and in the tubers. Current breeding programs are attempting to segregate the factors that affect foliage and tuber alkaloid content levels. However, at the current time there is no easy analysis for these compounds. Until there is an economical method available that can be used to screen the large populations of cultivars under development, breeding programs for the

development of glycoalkaloid based resistance are not feasible. The use of this type of resistance mechanism, even if it were available in commercial cultivars, may be subject to the development of resistance by the target insects through the selection of host-specific strains of insects that can withstand increased glycoalkaloid levels.

The second major arthropod mechanism of insect resistance, glandular pubesence, appears to have less serious limitations for use as a pest management tool. It can be relatively easily assessed through the use of simple microscopy, and in the later stages of selection, through the use of measurement of phenolic oxidase levels.

While the development of host resistance against insects as a component of an IPM system for potatoes is possible, currently available cultivars for use in Ontario do not show significant resistance to the major insect pests. As resistant cultivars become available, their use should be incorporated into an IPM program.

5.1.4 Cultural Control Measures

A variety of cultural control methods is being used to reduce insect populations and/or to develop a plant that is more tolerant and able to compensate for insect attack. A summary of the methods available is provided below. Some of these recommendations are supported by research data, others are simply good agronomic practices.

Crop Rotation: The use of crop rotation as a standard agronomic practice has many advantages over continuous cropping, including the reduction of losses due to insects. Crop rotation from potatoes to a nonhost crop and back to potatoes has been shown to reduce populations of the Colorado potato beetle in comparison to fields where continuous cropping was used. Studies on Long Island (Wright, 1984) indicated that

first generation populations can be reduced by 60% to more than 90% in fields using crop rotation. Fields using crop rotation used an average of 1 (range 0-2) less foliar insecticide application against the first generation of the Colorado potato beetle. The effect of crop rotation was greatest early in the season, and was not detectable after the first generation.

Seed Quality: A strong healthy seedling results in good initial plant development and increased ability of the plant to withstand attack. Seed should be stored at 3-4°C. Cooler temperatures can reduce seed vigor. The use of sprouted seed can reduce the time between planting and seedling emergence. This may provide additional time for the seedlings to become established prior to insect attack. However, excessive sprouting, i.e. greater than 0.5 cm, before planting can reduce vigor and increase handling problems in cutting of seed and planting. The ideal seed piece size is 50g (range 45g - 60g) and smaller seedpieces should be kept to a minimum. A sprout from a large seed piece can tolerate much more defoliation than a small seed piece, and has the reserves to produce additional sprouts. Seed treatment is also recommended to help prevent seed decay, and to aid in the development of vigorous seedlings. When 2-3 days are allowed after cutting for suberization of wounds, increased stand density and reduced losses due to seed piece decay result. The use of whole seed rather than cut pieces has been shown to substantially decrease losses due to seed piece decay, and aids in producing a vigorous seedling. The trend to produce and use smaller "B" size seed should be encouraged.

Plant Emergence: Soil covering the seed piece should be no greater than 5 cm deep. Deep soil delays emergence of the seedlings and increases the probability of problems associated with cold, wet soil and lack of oxygen. Shallow covering with soil can increase emergence by as much as 7

to 14 days, again helping to produce a vigorous seedling. If there is concern over the effects of a late frost, deep hills can be left until one or two weeks after planting and then "knocked down" with a log chain attached to each disc.

Planting Date: Late plantings should be avoided so that seedlings are not exposed to the full brunt of defoliating insects before they are well established. This is especially true in fields that have not been rotated and fields that are planted with late maturing varieties.

5.1.5 Insecticides

The use of insecticides has been, and in the forseeable future will continue to be, the major control tactic available for the control of insects on potatoes. The problems associated with the use of these products must be addressed as part of an IPM system, namely: insecticide resistance, potential ground water contamination, negative effects on biocontrol agents in potato fields, increasing costs, and environmental pollution. A variety of techniques has been suggested to delay or minimize these problems:

(1) To prevent or delay the development of insecticide resistance it is strongly recommended that the insecticides used be alternated between groups with different modes of action. It is also suggested that a different group of insecticides be used against each life stage, eg. larvae vs. adults. The use of mixtures of insecticides to control insects is not recommended, as such a practice may result in the development of resistance to each component of the mixture at the same rate as if each was used separately.

(2) Insecticides should only be used when necessary, i.e. as based on pest monitoring information indicating when threshold levels have been

exceeded and economically significant losses would otherwise occur. Only registered rates should be used so as not to promote the rapid development of resistance.

(3) Alternative control methods should be used as much as possible, so as to remove the selection pressure exerted by the insecticides. However, the only practical alternatives that are currently available for use are the cultural control techniques discussed above. These cultural methods alone will not provide the necessary degree of control required in most instances.

(4) The insecticidal nature of some herbicides may also be optimized and the use of vine-killers applied at optimum timing may interrupt Colorado potato beetle life cycles by causing chemical poisoning and/or starvation.

5.2 DISEASES

5.2.1 Pest Monitoring Techniques and Economic Thresholds

Many foliar diseases of horticultural crops require specific combinations of moisture and temperature for rapid development. The use of forecasts to time fungicide application is analogous with the use of economic threshold levels to time insecticide application. Monitoring weather, temperature and rainfall replaces population monitoring. Monitoring the incidence of the pathogens themselves can be very difficult due to technical limitations.

Blightcast, originally developed at Pennsylvania State University (Krause et al. 1975) is a forecasting program developed for late blight on potatoes. It is based on two older forecasting techniques (Hyre, 1954; Wallin, 1962). This program has met with mixed results in terms of optimizing the timing and use of fungicides. For example, from 1973 to

1975, in Ithaca, New York, potato plots sprayed according to Blightcast received fewer fungicide applications (6 applications/season), and were equally protected from late blight as were plots sprayed weekly (10 applications/season). However, on Long Island, New York, weather is almost always favorable to late blight. The five day interval recommended by Blightcast for these conditions is more frequent than the standard weely applications made by growers in the region that provides adequate control. Thus, while the program was useful in the Ithaca potato growing region, it was not useful in the Long Island region (Fohner et al., 1982).

In order to make the program more useful, several changes have been made to incorporate the factor of plant resistance to late blight into the Blightcast program. When weather is particularly favorable for the development of late blight, fungicide applications were recommended for susceptible varieties on a five day interval vs. seven days for a more resistant variety. Similarly, when weather is moderately favorable to late blight development, fungicide applications were applied every seven days to susceptible, and nine days to resistant varieties.

In New York, Cornell University has ranked many of the varieties commonly grown in Ontario by their susceptibility to late blight (Table 19). The recommendations state that fungicide should be applied to susceptible varieties at least every 7-8 days, to moderately susceptible varieties every 8-10 days, and to moderately resistant varieties every 10-14 days. The higher frequency is recommended in weather that favors blight development, i.e. high humidity and rain with moderate temperatures. These recommendations also suggest that frequency of application and the amount of fungicide applied may be adjusted according to the fungicide (Spadafora et al., 1984). It is recommended that

Mancozeb, Dithane M-45 or Manzate 200 and metiram (Polyram) be applied more frequently, but captafol (Difolatan), chlorothalonil (Bravo) which are more tenacious, i.e. degrade or wash off more slowly, may be applied less frequently. In this scheme, Blightcast was not being used to recommend actual application frequencies as it recommended more intensive use of fungicides than was necessary.

TABLE 19. Ranking of Potato Varieties for Susceptibility to Late Blight

Susceptible*	Moderately Susceptible	Moderately Resistant	Resistant
Chippewa	Russet Burbank	Rosa	NY 59
Russet Rural	Green Mountain	Kennebec	
Abnaki	Atlantic	Sebago	
Norchip	Katahdin		
Monona	Bake-King		
Belrus	Frito-Lay 657		
Chieftan			
Belchip			
Hudson			
Superior			
Wauseon			

* Within each category, varieties are ranked from the top down from most susceptible to least.
Source: Halseth et al., 1983; Fry, pers. comm.

A modified control strategy for late blight has been used for the last three years in New Brunswick, and for the first time this season in Prince Edward Island. This strategy has been under development for some time, and is currently being developed by Dr. J. Holley, Agriculture Canada, Fredericton, New Brunswick. Relative humidity and temperature data, collected twice each week with thermohygrographs located in growers' fields, are used to calculate a late blight warning index for 16 major potato growing regions in the Atlantic provinces. The index indicates when conditions are favorable for the development of blight. Reports on disease incidence and severity are combined with the calculated blight

index to formulate spray interval recommendations for each of the major potato growing regions. Combining weather data with daily reports from scout observations in fields on disease progress, provides a unique approach to disease forecasting. This approach has resulted in reduced fungicide applications in seasons unfavorable to late blight and improves control by providing advanced warning of serious disease pressure.

From the above it is evident that there is a variety of potential pest monitoring techniques to recommend fungicide application for the control of late blight. However, in view of the importance of early blight, and interregional differences between potato growing regions in Ontario, the usefulness of the above methods in an IPM program would have to be assessed on a regional basis. For example, late blight monitoring may not be considered useful in the Alliston region where early blight is considered the major problem.

A system to forecast when foliar applications of fungicide should be initiated for control of early blight has been developed for tomatoes. This has been shown to optimize fungicide use by delaying the initiation of fungicide treatments, and increasing the period between fungicide applications (Pennypacker et al., 1983; Madden et al., 1978). This program could be modified for use on potatoes.

In Ontario, several attempts have been made to test a potato blight monitoring system in the Alliston area. The initial work focussed on late blight monitoring, while more recent work has been done on early blight. This occurred due to the increased planting of Norchip that is highly susceptible to early blight as well as late blight. These trials have indicated that fungicides can be used more efficiently when monitoring is undertaken. Information available would recommend the time of initiation of fungicide applications and possibly the interval between applications.

5.2.2 Potential Control Techniques

Potential control techniques for use against late blight in an integrated pest management program include host resistance, cultural control methods and the use of fungicides.

Host Resistance

Some potato clones do not support as prolific development of late blight as do other clones. Two types of resistance to late blight in potatoes are recognized. These are specific resistance (race specific, vertical or monogenic resistance) and general resistance (horizontal or polygenic resistance). An extremely high level of specific resistance that almost totally suppressed late blight development was identified early in the 1900's. This resistance was conferred by a single gene from Solunum demissum (Ferris, 1955; Van der Plank, 1963). Unfortunately, the ability to overcome or avoid the effects of this gene appeared quickly within the late blight population. Other single gene resistance was overcome by the pathogen population within a few years of large-scale use (Neiderhauser and Cobb, 1959; Thurston, 1971). The genetic variability within the pathogen population is sufficient to render single gene resistance relatively useless.

Other potato clones have lower levels of general resistance in which the development of the pathogen is slowed but not prevented (Fry, 1981). For example, the cultivar Sebago is more resistant than other commercially grown varieties (James et al., 1973; Fry, 1981). The mechanisms of this nonspecific resistance are quite varied (Allen and Friend, 1983; Hohl and Stossel, 1976; Shimony and Friend, 1976), but generally involve reduced hyphal growth and/or reduced penetration of plant tissue. Breeding efforts are ongoing to incorporate general resistance to late blight into more commercially available varieties.

In addition to the use of host plant resistance to reduce the effects of late blight, varieties have been developed with resistance to a variety of other pathogens that attack potatoes. Varieties have been produced that show resistance to scab, verticillium wilt, early blight, silver scurf, and several viruses. Those varieties commonly grown in Ontario with resistance are indicated in Table 11.

The development of potato varieties resistant to insects, diseases and nematodes is significantly restricted by the time and finances required. On average, it requires the development and screening of 200,000 seedlings to find a variety that is worthy of release, and 1 million seedlings to find a variety that will be used by a significant proportion of potato growers. This usually requires 15 or more years, and several hundred thousand dollars. The incorporation of multiple pest resistance into new varieties is highly desirable, however, breeders must incorporate a long list of other characters into new varieties, including: high yield ability, cooking quality and flavor, pleasing shape, skin color, good storage characteristics, tuber size, freedom from toxic chemicals (eg. glycoalkaloids) and various other factors. Generally, more weight has been given to the incorporation of many of these characters into potato varieties than the incorporation of resistance to pests. In some cases, this has resulted in potato growers having to rely more heavily on the use of pesticides, eg. fungicides to control late and early blight on Norchip.

Cultural Control Techniques

A variety of cultural control techniques can be used to aid in the control of potato diseases.

Use Of Certified Seed: The use of certified seed guarantees a minimum of disease introduction into a field from the seed itself. This

is of importance in reducing the initial inoculum of a variety of diseases including: late blight, early blight, bacterial ring rot, viruses, etc.

Crop Rotation: Crop rotation provides reduced pest problems in general. It is of major importance in reducing the incidence of soil-borne diseases attacking potatoes, including verticilium wilt, fusarium wilt, common scab, late blight and early blight. However, crop rotation also can cause pest problems, eg. wireworms, white grubs and seedcorn maggots.

Manipulation Of Soil pH: Common scab generally does not occur on soils with a pH below 5 but may be quite severe in soils with a pH of 6 or above. The use of sulfur to reduce soil pH can control scab, although this is seldom economically feasible. The use of lime on soils should be avoided as it could raise the soil pH above 5.

Sanitation: Disease inoculum sources such as cull piles should be destroyed. All knives and implements used for cutting, handling and planting seed should be thoroughly cleaned and disinfected.

Vinekilling: If foliage does become infected with late blight late in the growing season, tuber infection can be prevented or greatly reduced by killing the vines at least two weeks before harvest. This prevents further infection, and infected tubers will rot in the ground sufficiently so that they will not be harvested. Before storage, tubers should be carefully examined and infected tubers discarded.

Fungicides

Fungicides will, for the forseeable future, remain the cornerstone of foliar disease control in potatoes. To prevent or delay the development of resistance, fungicides should only be used when necessary, with use based on pest monitoring information and thresholds. This is especially true when the specific systemic fungicides, such as metalaxyl

are used. The mode of action of these systemic eradicant fungicides is highly specific, thus increasing the opportunity for the development of fungicide resistance. To delay the development of resistance to metalaxyl, it has been formulated as a mixture with maneb. However, it is the opinion of some that the mixing of these two active ingredients may increase the rate at which resistance develops. Most agree that metalaxyl should only be used when its eradicant properties are required, i.e. if the protectant fungicides are not able to provide foliage protection.

5.3 WEEDS

5.3.1 Pest Monitoring Techniques and Economic Thresholds

Pest monitoring techniques and the use of economic thresolds for control of weeds have not been developed in most crops including potatoes. Monitoring, at the current time, usually refers to weed identification rather than weed population counts.

5.3.2 Potential Control Techniques

The control techniques available for weeds in potatoes include cultivation, the use of competitive potato varieties, and herbicides.

Cultivation has been an important part of potato production for both its ability to provide weed control, and the hilling process that is required to protect developing tubers. In current potato production systems, cultivation is primarily used for the latter purpose and used to control "escapes", i.e. weeds that were not controlled by herbicides. Increased use of tillage for weed control as part of an integrated pest management program would not be encouraged due to the potential negative effects of tillage.

Characteristics that enhance the ability of potatoes to compete successfully with weeds are early emergence, rapid growth early in the

season, and the ability to maintain a dense canopy throughout the growing season. Potato cultivars vary in these characteristics, making some better competitors than others (Nielson and Thorsen, 1981). Yip et al/ (1974) and Sweet et al., (1974) have shown that potato varieties such as Hudson and Green Mountain are much more competitive with weeds than varieties such as Norchip, Sebago and Katahdin. In addition, the use of good cultural practices to provide fast, uniform and vigorous development of the crop allows any variety to be more competitive, and to develop a full canopy earlier in the growing season. Once a full canopy is formed, it results in minimal light penetration and thus impedes the development of new weeds.

The use of herbicides will be of major significance as a component in an IPM program. In terms of weed control, the alternatives to herbicides are limited, however, improvements can be made in the use of herbicides. IPM can provide weed identification services, and information concerning the proper selection of herbicides and timing of applications. With the availability of the post-emergence grass herbicides Fusilade and Poast, the potato grower is now given the opportunity of waiting to see if, and where there is a grass problem, and then treating only those areas that require treatment. Prior to the availability of these herbicides, the only herbicides available that provided adequate control were pre-emergent herbicides that were often applied with little knowledge as to whether or not there was a significant grass problem.

5.4 NEMATODES

5.4.1 Pest Monitoring Techniques and Economic Thresholds

Pest monitoring techniques and economic thresholds are well developed for nematodes in potatoes. Soil samples are usually used to

identify fields that have significant nematode populations. The soil samples should be taken with a soil sampling tube, trowel or narrow bladed shovel. Soil should be sampled to a depth of 25 cm. In bare areas, the top 2 cm of soil should be scraped away prior to sampling. Each sample should consist of 0.5-1 liter of soil, preferably taken from a larger sample composed of 10 or more subsamples. The number of subsamples taken depends on the size of the area to be sampled. Small areas, less than 500 square meters, require at least 10 subsamples; medium areas, 500 square meteres - 0.5 hectares, require at least 25 subsamples; and large areas, 0.5-2.5 ha, require at least 50 subsamples. No one sample should represent more than 2.5 ha, and each sample should be from an area of uniform soil type. Subsamples should be thoroughly mixed, a sample taken, placed into a clean plastic bag and submitted for analysis. The subsamples themselves should be taken in the fall or spring. The actual soil analysis for nematodes involves extraction of the nematodes from the soil and microscopic analysis of the extract. The nematodes present are identified, counted and recommendations made on the basis of the economic thresholds discussed below. This service is currently available in Ontario to potato growers.

The economic thresholds established by Olthof and Potter (1972) in Ontario are 666 root knot nematodes/kg of soil. This threshold is based on a loss of 5% of marketable yield, approximately the cost of fumigation. Economic thresholds established by Olthof and Potter (1973) for the root lesion nematode in Ontario are 2,000-6,000 nematodes/kg of soil. The economic threshold is based on a loss of 7% of marketable yield to compensate for the costs of soil fumigation.

A survey of 50 potato fields in the Alliston region (Olthof et al., 1982) found the root lesion nematode in 32 fields, and the root knot

nematode in 12 fields at mean densities of 1695 and 655 nematodes/kg of soil. These were the two dominant species found in the survey. Sixteen of the fields infested with root lesion nematodes had populations that exceeded the economic threshold, and six of the fields infested with the root knot nematodes exceeded the economic threshold, i.e. 44% of the fields surveyed had nematode populations that would be expected to cause economically significant damage. Despite this, treatment for nematodes in potatoes in Ontario is rare. One of the significant problems limiting treatment is the ability to accurately identify those fields, or the portions of fields that do require treatment. While economic thresholds are available, there are problems with their use as discussed below.

While soil samples taken in the fall before growing potatoes may indicate populations below the economic threshold, by spring, populations may have increased to economically significant levels. For example, a rye cover crop and a mild winter may result in increased nematode populations. The converse may also occur, i.e. populations may be above the economic threshold in the fall, yet decline to much lower populations by the spring if there has been a severe winter. If spring soil samples are taken, a very large testing facility would have to be available to rapidly process the samples and provide growers with results in time to allow application and dissipation of the soil fumigants. Thus, the logistics of sampling, the low unit crop value, and the time required to apply and dissipate soild fumigants have resulted in the low hectarage of potatoes treated with soil fumigants.

5.4.2 Potential Control Techniques

Cultural, genetic, and chemical control methods may be used to reduce losses from nematodes.

Crop rotation has been the primary cultural control method used that results in reduced nematode populations. For crop rotation to be effective, a series of nonhost plants is grown in rotation with potatoes, however, there are several problems with this method. It is difficult to find economically viable crops that are not hosts to one, or both, of the root knot or root lesion nematodes. For example, while grasses and grains do not support the root knot nematode, most of them are preferred hosts of the root lesion nematode. In addition, a rotation of several years through nonhost crops is required to successfully reduce nematode populations, i.e. at least 3-4 years for the root lesion nematode and 5 years for the root knot nematode. It is usually not possible to have land out of potato production for this time period. In reality, many potato growers grow "continuous potatoes", i.e. no rotation at all, resulting in increased nematode populations.

The use of resistant potato varieties provides another possible method to reduce the effects of nematodes. This is a subject of active research by T.H.A. Olthof, Agriculture Canada Research Station, Vineland. Some cultivars of potatoes are not as susceptible to attack by the root lesion nematode, eg. Yukon Gold vs. Superior, (Olthof, 1983) or Russet Burbank vs. Kenebec and Superior (Bernard and Laughlin, 1976). However, varietal selection by growers is usually based on other factors than resistance to nematode damage.

While soil fumigants provide the greatest efficacy of the control methods available, they are not often used due to the problems discussed above. An IPM program with spring soil sampling and analysis may aid in the detection of fields that do require soil fumigation or the use of alternative control methods.

6. POTENTIAL OF IMPLEMENTATION OF IPM ON POTATOES

The goals of an IPM program, in the authors' view, are to a) reduce the risk of losses due to pests; b) optimize returns to currently available pest control methods; c) implement diversified methods of pest control so as to produce a more stable production system. Within this context a variety of other benefits may accrue including: a) decreased occupational exposure to pesticides; b) decreased pesticide residues in produce; c) decreased environmental contamination with pesticides; and d) delay in the development of pesticide resistance. To properly assess whether an IPM program in potatoes can be initiated at the current time, the technology available must be viewed with these goals in mind. In addition, the technology should be compared to the technology in use in other IPM programs in Ontario and the ability of these programs to achieve the above goals.

Current IPM programs in Ontario are primarily pest monitoring programs, and are thus based on the development and use of pest monitoring techniques and "economic thresholds". Therefore, the initiation of any program in potatoes will require the availability of pest monitoring techniques and thresholds. In general, pest monitoring techniques and economic thresholds do exist for the major pests attacking potatoes, however, they have not been tested in Ontario. The use of pest monitoring technology and economic thresholds provides the means of achieving reduced risk of losses due to pests and optimizing currently available pest control techniques.

At the current time, the monitoring of pesticide resistance could be made a component of the IPM program. This would provide growers with warning as to if and when resistance develops to either insecticides and

fungicides. This would result in avoidance of losses if pesticide resistance develops. In addition, the more judicious use and selection of pesticides under an IPM program may result in the delayed development of resistance.

For the major pests of potatoes in Ontario, there are few currently available alternatives to the use of pesticides, and those that are available have not been tested in Ontario. Before their recommendation as a component of an IPM program in Ontario, they would have to be tested in large scale research plots.

6.1 EFFECT OF AN IPM PROGRAM ON POTATO PRODUCTION

Due to the inter- and intra-regional variation in pest problems in potatoes in Ontario, the variability in pest control tactics currently in use, and the lack of information concerning the use of pest monitoring, economic thresholds and alternatives to pesticides, it is very difficult to predict the effects of the use of pest monitoring on pesticide use by growers. It would be expected that growers who rely on foliar applied insecticides, rather than a granular applied at seeding, would receive the greatest benefits. This is due to the fact that insecticides would be applied only when necessary, and not as part of an application schedule. Growers who had applied a granular at seeding would be provided with indications as to how well the granular was working and when a foliar application was required. Foliar fungicide applications may be reduced by the use of modified "Blightcast" technology, or the use of a monitoring strategy for early blight, although this would be very dependent on local weather conditions, varieties grown, time of planting and harvest, etc. The effects of other diseases may also be reduced through the use of improved cultural control methods. Herbicide use would only change to a

minor extent due to the implementation of an IPM program, although the use of some herbicides could be improved.

On a long term basis, an IPM program could introduce a variety of control tactics to growers such that a more integrated form of IPM would evolve. In this fashion, biological, cultural and genetic control tactics could be introduced, thereby improving the stability of the crop production system.

In the authors' opinion, an IPM program in potatoes may achieve the goals discussed above, however, the available technologies must be tested under Ontario conditions before a large scale IPM program can be implemented.

6.2 POTATO MANAGEMENT PROGRAM

Discussions with extension personnel, agrochemical dealers and potato growers indicate that potato growers are interested in more than an IPM program. Rather they are interested in receiving a series of services within a crop management program. These services include soil fertility analysis (soil tests and leaf tissue analysis, irrigation recommendations and monitoring and analysis of storage problems, as well as IPM. A program has been initiated by Simon French and Andrea Meresz of Crop Tech Laboratories and Complete Farm Service in Alliston that provides the above services to growers. Growers pay for each component of the crop management service that they are interested in. A description of the services available is included in Appendix 2.

The pest management service that is currently offered is severely limited by the lack of information concerning pest monitoring techniques and thresholds for use in Ontario. The people involved with this program are willing to cooperate with researchers to improve the technology that they are using.

The question as to whether or not an IPM program should be commenced on potatoes in Ontario is somewhat academic, due to the offering of this service in the Alliston region by Complete Farm Service. However, the absence of information concerning the effectiveness of pest monitoring techniques and relevance of published economic thresholds to the Ontario situation places this IPM program on insecure footing. To avoid costly errors, these technologies must be tested thoroughly prior to a large-scale program. If these technologies were thoroughly tested, the information gathered would aid the grower in making a decision for optimum pesticide use. Many potato growers are currently basing their insecticide and fungicide applications on regular schedules rather than on pest incidence in the field. The demand for this service, as evident by the number of hectares of potatoes on the program in the Alliston region (ca. 2,500 ha) is very strong. It is necessary to ensure that the program available is based on sound research and tested technology.

RESEARCH RECOMMENDATIONS

1. Available pest monitoring technology and economic thresholds for insects and diseases must be tested under Ontario conditions. The authors suggest that this be done in conjunction with the currently existing IPM program in the Alliston region.

2. The use of alternative control techniques that are currently available as components of a commercially viable IPM program must be tested under Ontario conditions. This would probably require large plots, at least several hectares, that could be manipulated by researchers throughout the growing season using a combination of cultural, genetic, biological, etc. control techniques for insects, diseases, nematodes and possibly weeds.

3. A pesticide resistance management scheme for insects and diseases should be developed for use in potatoes. This should involve a resistance monitoring service, as well as a scheme of insecticide and fungicide use that would delay development of resistance.

4. Alternatives to the intensive use of pesticides should be explored. While this is an all encompassing statement, these alternatives must be developed to ensure the long term stability of potato production in Ontario. The most likely alternatives or additions to the currently used methods include host plant resistance, cultural control techniques, and biological control techniques.

5. The possibility of developing a laboratory to provide the rapid analysis of soil samples for nematodes should be explored.

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PERSONAL COMMUNICATIONS

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APPENDIX 1

PARTICIPANTS IN THE SCIENTIFIC MEETING, SEPTEMBER 1984 TORONTO, ONTARIO

Participants in the potato IPM scientific committee meeting, 24 September, 1984, Toronto, Ontario:

Armstrong, Les:	Ont. Potato Board, Burlington, Ont.
Casagrande, Richard	Dept. of Plant Pathology/Entomology, University of Rhode Island, Kingston, R.I., U.S.A.
Chisholm, Alex:	OPAC.
Costen, Ron:	Chipman Inc. Stoney Creek, Ont.
Drowley, Brad:	OPAC.
Harris, Ron	Agriculture Canada Research Station, London, Ont.
Heiymans, Rudi:	Ont. Reg. Potato Commission, Guelph, Ont.
Holley, Jim:	Agriculture Canada, Fredericton, N.B.
Hunter, Craig:	OMAF, HRIO, Simcoe, Ont.
Kinoshita, Garry:	Cyanamid Canada Inc. Willowdale, Ont.
Lucas, Joe:	Hazardous Contaminants. O.M.E.
Madder, Jim:	380 Woolwich St., Guelph, Ont. N1H 3W7
McDonald, Mary Ruth:	Muck Research Station, RR#1, Kettleby, Ont.
McLeod, Glenn:	Agr. Canada Research Station, London, Ont.
Muir, Earl:	OPAC.
Nurse, Mike:	Ciba-Geigy, Canada.
Pitblado, Ron:	Ridgetown College of Agricultural Technology, Ridgetown, Ont.
Potter, John:	Agriculture Canada Research Station, Vineland, Ont.
Roberts, Wayne:	OMAF, Guelph, Ont.
Sears, Mark:	Dept. of Environmental Biology, Univ. of Guelph.
Solomon, Keith:	Can. Toxicology Centre, Guelph, Ont.
Squire, Sam:	OMAF, Alliston, Ont.
Stemeroff, Marvin:	380 Woolwich St., Guelph, Ont. N1H 3W7
Tolman, Jeff:	Agr. Canada Research Station, London, Ont.

APPENDIX 2

POTATO CROP MANAGEMENT PROGRAM

(Crop Tech Laboratories, Alliston, Ontario)

Potato Crop Management Programme

Proposal #1

This programme will include:

(1) Pest management (Monitoring of insect populations, plant diseases, nematodes, and weeds)
(2) Soil fertility analysis, based on:
    (a) soil tests (nutrients)
    (b) leaf tissue analysis
(3) Irrigation recommendations, for those growers who irrigate their fields

Because the program will begin this spring (1985) fertility recommendations will be based on last year's soil sample test results. In the fall of 1985, soil samples will be taken by Elm grove crop service, and analyzed by Crop Tech Laboratories. Fertilizer recommendations for the following year will be based on those soil test results.

After seeding, the grower will be asked the following questions about each field he is having monitored. The questionnaire will be composed of 3 parts, covering:

(1) general management
(2) pesticides
(3) fertilizer

Part (a):

1. Potato variety and seed source: e.g., -certified
   -foundation
   -last year's stock

2. Seed treatment: whole vs. cut seed
   dust: -easeout
   -gypsum

3. Planting date

4. Seed spacing & depth

5. Planter type: -pick
   -cup

6. Expected yield

7. Crop rotated within the last two years- if potatoes, which variety

8. Problems last year: -insects
   -disease
   -weeds
   -nematodes
   -storage problems
   -low yield

9. Type of sprayer: -aerial
   -nozzle types

Part (b):

1. Herbicides used on potatoes in previous years
   This year: pre- or post plant

2. Insecticides used on potatoes in previous years, & approx. # of applications:
   This year: pre plant granular -Temik
   -Disyston/Thimet
   -rate granular applied
   -did insecticides give adequate control- if not, any possible reasons why they failed

3. Fungicides used on potatoes in previous years, and approximate number of applications

   -did they give adequate control- if not, any possible reasons why they failed
   -were there any storage problems

4. Has the field been fumigated before- if so, with what, and did the fumigant used work

Part (c): (Includes a map of each field)

1. Type of soil (e.g., heavy clay, sandy loam, etc.)

2. Is the field relatively homogeneous- if not, where are the "different" spots, and what are they composed of (e.g., sandy knolls, etc.)

3. Is the field fertilized with the same mix (i.e., are there areas which are fertilized differently)

4. Are there any problem areas in the field- e.g., high pH, poor drainage, soil compaction, etc.

5. Direction field worked (vs. direction planted)

6. Direction fertilizer was spread, and method of application (e.g., broadcast)

7. Type of equipment used to spread fertilizer

8. Ploughing depth- is this constant from year to year

After the grower has planted the seed, the scout will check the fields for the emergence of the vines. The scout will the mark off 50 plants in each of 4 rows, using yellow marker flags. In fields of potatoes less than or equal to 40 acres, there will be 5 such plots; in fields larger than 40 acres, there will be 10 plots. In fields grown for seed, there will be 10 plots, irrespective of the size of the field.

In addition to these plots, there will be 10 pheromone traps placed in the north-west corner of each field. These will be used to monitor populations of adult cutworms (5 traps for the black cutworm, and 5 traps for the vareigated cutworm).

In fields of potatoes grown for seed, there will be 5 yellow pan traps placed in the field to monitor early aphid flights.

As the scout walks through the field, they will randomly choose 10 plants from each check plot, and check one upper, middle and lower leaf from each plant. Plants will be observed for:

(a) leafhopper nymphs
(b) Colorado potato beetle
(c) flea beetle
(d) aphids
(e) cutworm damage
(f) signs of disease

Therefore, a total of 50 plants will be sampled in fields of less than 40 acres, and 100 plants will be sampled in fields of seed potatoes and fields larger than 40 acres.

As the scout-walks to each plot, he/she will make 10 sweeps with a sweep net. This will determine the populations of adult leafhoppers and tarnished plant bugs. In addition, the scout will be looking for signs of disease in the crop, and areas which show irregular or poor growth of the potatoes.

50 sites will be randomly chosen from the field, from which leaf tissue samples will be taken. These sites may be marked with different coloured flags and petiole samples taken from a plant near the flag. The scout will take petiole samples each week for 6 weeks, starting when the plants are 20cm high. In addition, soil samples may be taken from the same area.

Insect counts will be reported to the grower as soon as the field is scouted. The scout will try to locate the grower each time the field is scouted, to tell him how each field is in terms of pests and diseases. The scouts should not be allowed to make pesticide recommendations, but can advise the grower if there are signs that insect populations are increasing or if there is disease in the crop.

Insect counts will be graphed on a chart which is to be placed in an area accessible to the scout and grower, e.g., a machine shop or storage barn. For those insects which have an action threshold, these will be indicated on the graphs, and spray recommendations made if the populations increase beyond these. Growers will be asked to provide a record of their spray schedule. This will be useful for two reasons- Firstly, the spray dates can be marked on the chart, the grower can easily assess the impact insecticides have on the insect populations in his fields. In addition, the scout will be forewarned if a grower is going to spray his field, and scout it on a different day.